# EVERYDAY PROBLEMS IN SCIENCE

BEAUCHAMP · MAYFIELD · WEST

Barbara Kostinuk
St. James
Collegiate
Rm. 10-D Grade X

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Lydia McRae

Bill were here

Bill were there

Bill were everywhere

Three things used in N.B. starting fire
Fuel
Oxygen
ignition temperature

~~Ten & Tomatoes~~

Red Head & Black Head,
White & continuations

Just three minutes after an atomic bomb exploded on August 10, 1945, this huge column of smoke had risen more than 20,000 feet, or about four miles, above the earth. In an instant most of a large city was wiped out, and thousands of men, women, and children were killed or seriously injured. Scientists had discovered how to get vast quantities of energy from matter. The picture shows what can happen when a scientific discovery is put to a destructive use. Unless the peoples of the world can learn to live in peace, they now have the means of destroying themselves at will. (INS photo from U.S. Army Air Forces)

BASIC STUDIES IN SCIENCE

# Everyday Problems in Science

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# Finding the Meanings of Things

DID YOU LOOK AT THE FRONTISPIECE of this book? The frontispiece is opposite the title page. On it you will find a picture about science that was printed in newspapers and magazines. If you did not look at this page very carefully, turn to it now and read what is printed under the picture. Are there any words whose meanings you do not know? Do you know what *atomic*, *energy*, and *matter* mean? Are there any ideas that you do not understand? For example, do you know what an explosion is? Do you know how a scientist might discover some important new fact about the world in which we live? Do you understand why we must learn to use scientific discoveries wisely?

Every day in the newspapers and magazines of our country there are many stories about science. These stories tell of the discoveries that scientists are making about the world in which you live. Some of these discoveries are so important that they are changing your life and the lives of millions of other people. Yet you cannot read these stories and understand them unless you know the meanings of science words and have accurate science ideas.

But understanding science in newspaper and magazine stories is not the only reason for learning science. The winds blow, rain or snow falls, you become ill with some kind of sickness, you pour hot water over a glass and the glass breaks, you try to learn to float in water, and in countless other ways you meet science every day of your life. What do these happenings mean to you? Do you understand what makes them happen?

Almost ever since you were born, you have been trying to find out what things mean. You probably pestered your parents by

asking "Why?" "What is it?" "What makes it go?" "Where did it come from?" etc. You were trying to find the meanings of things. The science that you will study in this book will make the world mean much more to you. You will study about the sun and the stars, earthquakes and glaciers, submarine boats and disease germs, muscles, bones, eyes and ears, aeroplanes, Diesel engines, radios, and soil conservation. If you use this book right, hundreds of things that have never before meant anything to you will really mean something. Of course you realize that the knowledge in this book is only a beginning in the field of science. In your future school years you may study more specialized branches of science if you wish: about living things in *biology*, about plants in *botany*, about animals in *zoölogy*, about human beings in human *physiology* and *anatomy*, about the solar system and the stars in *astronomy*, about the earth and its changes in *geology*, about force and energy in *physics*, and about chemical changes in *chemistry*.

THERE IS A SECOND THING that the study of this science material should do for you. People often say that the study of science should teach boys and girls to think. But that is not quite correct. You have been thinking for a number of years. You will probably go on thinking. But it is not so certain that you have been thinking correctly and that you will think correctly in the future.

This book can do much to show you how to think. As you read how scientists have solved important problems, you will be able to see how to use your own mind. As you work out the experiments, exercises, and problems in the book, you will have opportunities to do the kind of clean-cut, careful thinking that a scientist does when he makes discoveries about the world.

NOW THIS BOOK IS ONLY A TOOL TO HELP YOU do a job. The job is to understand the world in which you live and to learn how to think correctly. You know that you cannot do good work with a tool unless you know how to use it. Therefore you should, first of all, get acquainted with the way this book is made. The book is divided into twenty units. Look at the titles of the units in the table of contents so that you will get a big picture of what

you are going to study. Notice that the unit titles ask you questions about big and important parts of the science of the world you live in.

Each unit starts off with a part called *Looking Ahead*, which gives you a general idea of what the unit is about and tells you the big problems that you are to solve in your study of the unit. Then you come to the problems into which the unit is divided, thus, ¶ 1. *What kinds of problems do scientists solve?* The problems are divided into sub-problems. Each sub-problem asks an important question that you must be able to answer in order to solve the main problem. When you can answer each sub-problem, you can then answer the main problem.

As you read carefully through the problem, look up important words if you do not know what they mean or how to pronounce them. You will find a list of *Science Words*, beginning on page 715. This list tells how to pronounce the science words and explains what they mean.

Whenever possible, do the experiments in the unit. They will help you understand and remember the important ideas you will use to answer the problems. Sometimes you will do the experiments in the classroom or laboratory with your classmates. However, you can do many of the experiments at home. If you do not have just the kind of apparatus the directions call for, you can often use something else or do the experiment in a different way if you understand what you are trying to find out.

Scattered at various places in the unit are *Self-Testing Exercises*. Their name tells you what they are for. They help you check yourself to see whether you are really understanding the material you are studying. The exercises will be much better tests if you will try to do them without looking back in the book. After writing the answers as well as you can, it is a good plan to look back to be sure you are right, or to find the ideas you did not remember. When you have done all the *Self-Testing Exercises* that follow a problem or a sub-problem, write the answer to the problem itself. Every student should do at least this much before going on to the next problem.

In every unit there are also *Problems to Solve*. These problems are harder tests of your learning. Usually the answers can-

not be found in the book. You must think them out by using what you have learned. Or you must do some scientific research; that is, you must experiment, make observations, talk to people who have information that you need, or read books.

At the end of each unit is an exercise called *Looking Back*. This is a summary exercise to help you gather together the big ideas of the unit and to show you whether you know the meanings of the new science words. If you finish the unit ahead of your class, or if you have extra time outside of class, you will be allowed to do extra projects. You may then do some of the *Additional Exercises* at the end of the unit. The stories of the lives of scientists and of the things they have discovered are as interesting as any stories ever written. At the end of each unit is a list of books about science and scientists. They will tell you many things that are not told in this textbook, and you will be able to understand them because you have studied this textbook.

Talk with your teacher about your plans for independent work. He will often be able to suggest things to find out or to do about science in your own community. You can often help him, too, by finding things out for yourself and then telling the class what you have learned. The real success of your work in science will be shown by: (1) how much you learn about science; (2) how well you can use what you learn; (3) how well you learn to work without being told just what to do.

A VERY WISE MAN ONCE SAID, "To live is to change." You know one thing that he meant. You know that the body of every living thing constantly changes from the time it is born until it dies. But something else besides your body changes. Your mind changes, too. Every year you have new experiences, and from these experiences you learn things and get new ideas.

A few years ago the boys and girls of the science classes in a large city high school were asked to answer this question: "How has the study of science changed you?" Here are some of the things they said:

"I learned of the many ways in which man has harnessed nature to do his work. . . . By use of electricity he makes darkness into artificial light."

"The study of science led me to cross-pollinate flowers myself and watch the results."

"I bought a microscope to better continue my experiments."

"On trips now I look for fossils and evidence of change."

"I am now more interested in the habits of insects, flowers, and trees."

"In science I discovered how little I know."

"It made me want to see below the surface and know the inner, secret workings of things."

"All the theories given in science were backed up by evidence. It has made me look for evidence in everything."

"It taught me that only after many observations am I capable of making a true statement."

"Since studying science I don't say a thing is so, for sure; but as far as I know, it is so."

"I found that prejudice helps to twist the facts around and so makes the value of an experiment less."

"I learned that great men, like Aristotle even, had wrong ideas, and thus my own ideas were encouraged."

"I learned to work more systematically."

"I now read biographies of scientists and articles containing scientific facts, which before were of no interest to me."

"Now, with a knowledge of some science, I can enjoy and understand scientific discussions in books."

Most people think that the changes these boys and girls saw in themselves are good changes, and that is one reason why you have been given a chance to study science.

As you would expect, scientists have learned a great deal about the world in which we live—much more than we could possibly tell you in one book. But what is more important to you is this: The knowledge of how nature works has helped scientists and inventors to produce all sorts of new things—new varieties of plants and animals, water-wheels, complicated engines, automobiles, printing presses, electric batteries, generators and motors, and radio apparatus. All these inventions help man control the energy and materials of nature and make them do what he thinks he wants done.

But there is another side to man's use of nature. By cutting forests, cultivating land, and raising animals he has done what he thought was best, only to discover, after many years, that what he has done has ruined the land. In some parts of the world people are no longer able to live on the land or to enjoy its use as they once did. In this book you may read of some of these mistakes and what can be done to remedy them.

As you learn more and more about nature and man's use of it, keep in mind that the wonderful results of scientific knowledge are not all giving greater happiness and good to the world. In some ways they are raising serious problems that you may help solve. The use of energy in labor-saving machines has created a problem of finding work for everyone who needs it. Some of the most delicate, accurate instruments and some of the fastest and most powerful machines are being planned to kill innocent people.

Remember, then, as you study, that science is not solving all the problems of the world. Science is used by men and women, and the results of its use will be good only to the extent that men and women are wise and good. In your study of science and of other subjects try to find out what is wise and good so that you can help make the best use of scientific knowledge.

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SCIENTISTS USE MANY SPECIAL INSTRUMENTS to help them do their work. One of the newest instruments is a huge calculating machine that will help scientists solve problems about the world in which we live. It is called an electronic numerical integrator and computer. Using 18,000 vacuum tubes and miles of wire, it can add numbers in 1/5000 of a second and solve many mathematical problems 1000 times faster than any calculating machine previously built. Scientists at the Moore School of Electrical Engineering, University of Pennsylvania, designed this valuable instrument. (Science Service photo)

# UNIT 1

# How Do Scientists Work?

## Looking Ahead to Unit 1

WHEN WE THINK OF A SCIENTIST TODAY, we imagine a person surrounded with test-tubes, delicate measuring instruments, and bottles of strange substances. We see him bent over a microscope, carefully examining things that he could not see with his naked eyes. We see him in the chemical laboratory putting different substances together and taking other substances apart. These really are some of the things we would see if we visited a scientist at work today.

If we could have watched a scientist at work two thousand years ago, how different the picture would have been! Of course we would not have found a laboratory full of wonderful instruments, because most of the things we find in a science laboratory today have been invented in the last hundred years. However, the absence of test-tubes, microscopes, and other modern apparatus would not be the most important difference. Two thousand years ago men were studying the world carefully and thinking about the things they saw. But they did not think in the same way that scientists of today think. They had not learned true scientific ways of finding the facts about the things they saw. Before we find out how modern scientists work, let us see how the first scientists tried to discover the truth about the world we live in.

About 2200 years ago there lived in Greece a very great man named Aristotle. He was the most famous thinker of his time. Aristotle had noticed that a light object, such as a feather or a piece of paper, falls slowly to the ground, while a heavy object falls much faster. He thought this over and decided that heavy things fall faster than light things; that is, a ten-pound weight will fall ten times as fast as a one-pound weight. Having decided

Fig. 1. Scientists of long ago met in groups like this to talk about the things that happened in the world. They had no laboratories for experimenting. They decided what was true by thinking about the things they saw instead of by experimenting to prove whether their ideas were right or wrong.

this in his own mind, he taught it as a truth to his students. Because he was Aristotle, the wise man, his students believed him. You might think that Aristotle would have *experimented* to see whether heavy objects actually fall faster than light objects. But he did not do so. The early scientists never thought of experimenting. They would see something happen; then they would think about it and decide what it was or why it happened. But they never thought of testing their idea to see whether it was true. For over 1700 years after Aristotle's death, his ideas were accepted as the truth by almost everyone. Very few people even dared to doubt them.

It was a great day for science when a doubter came into the world—a man who did not believe everything he heard, a man who even doubted some things that the great Aristotle had said. This man was an Italian named Galileo, who lived 350 years ago. Among other things about which he was thinking, he doubted whether heavy objects fall any faster than light objects.

But Galileo was a different kind of thinker from Aristotle. He was not sure he was right until he had tested his idea. To do this

FIG. 2. Galileo was so famous as a thinker that people came from faraway countries to have him tell them about his discoveries.

he dropped a small ball and a large ball from the top of the leaning tower in the city of Pisa. Sure enough, they both hit the ground at the same time. He tried it again and again with other objects. At last he was sure that he was right. When Galileo told what he had learned, no one would believe him. Finally he persuaded a few men to come and see for themselves. Even then, they refused to believe what they saw with their own eyes. Because he would not believe some of the teachings of the great Aristotle, but thought things out for himself, Galileo was laughed at and even thrown into jail.

Today we praise Galileo and call him the father of modern science. He taught men how to think scientifically. He studied things carefully and described what he saw as accurately as he could. Then, instead of merely thinking out a reason for what he saw and being satisfied with his reasons, he experimented to get the facts that would prove or disprove the truth of his ideas. He refused to believe that a thing was true unless it had been proved to be true.

Now let us see just how scientists think and work. What is a "problem" in science? How do scientists find problems to solve,

and how do they go at the job of solving them? What is an experiment? What wonderful instruments have scientists invented to help them in discovering the secrets of nature? These are some of the questions for which you will learn the answers in this unit. In your study of science this year, you will be asked to do some scientific thinking. You will want to understand what "scientific thinking" means. If you learn how the scientist works, and if you get the habit of working in the way that the scientist does, the study of science will make you a better thinker.

## ¶ 1. What kinds of problems do scientists solve?

WHAT IS A "PROBLEM"? You have worked many arithmetic problems, and you know what they are. An arithmetic problem gives you some facts and asks you a question about the facts. You are to find the answer to the question. To find the answer you first choose the right way to work the problem. Then you do the work and check (test) your answer to see whether it is correct.

There are many other kinds of problems besides arithmetic problems. You have met and solved several of them already today. For example, suppose that as you started for school, you saw clouds piling up in the west. This made you think it might rain. You probably asked yourself this question, "Shall I wear my raincoat, carry an umbrella, or take a chance that it will not rain?" That was a problem to you because you did not know what to do. There were two or three different things you could have done. You wanted to choose the right thing to do.

Perhaps another problem you had to solve was whether you had time to go to your locker between classes. To solve the problem you considered how many minutes were left and how long it would take you to go to your locker and get what you wanted; then you decided whether you would have enough time.

Every day we all meet many different kinds of problems that we must solve. They are all alike, however, in one way: We are puzzled about something. We have to do something, but we do not know exactly what is the best thing to do. Or we want to know something, and we are not sure how to find out. In a

science problem we are trying to find the answer to some question about the world we live in.

A scientist is just a human being like yourself. He has the same everyday problems to solve that you have. Besides these problems of his own, he is keenly interested in the world we live in; he is always looking for an explanation of what he sees. He sees the sun rise and set, and he wonders why it appears in the east and disappears in the west. He pets a cat in the dark, sees sparks fly from the fur, and wonders what it is that makes the sparks. He sees "steam" shoot from a distant train whistle and a few seconds later hears the sound of the whistle. He wonders why he sees the "steam" before he hears the sound. These are all problems to the scientist. He wants explanations for them, and he is not satisfied until he has good explanations.

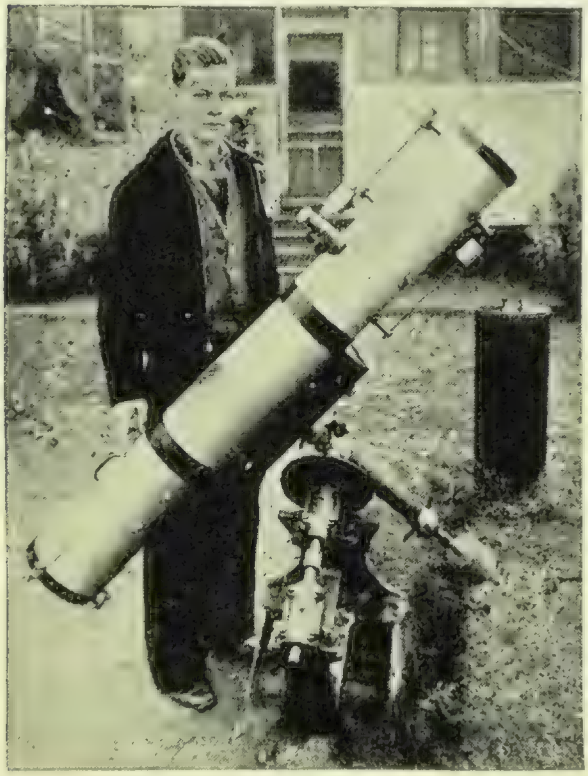

FIG. 3. Because Robert Lewis, a high-school student in Columbia, South Carolina, was interested in knowing more about the world, he made this telescope. With it he studied the sky and discovered a new star. (Wide World photo)

Many people do not see anything to explain in the decay of plants and animals, in the rising and setting of the sun, in sparks from cat's fur, and in the sound of a whistle. They are not interested in solving problems. They go through life with blind eyes and deaf ears. On every side they are surrounded with the wonders of the world. But they have no interest in what they see and hear. They are not like scientists. Scientists are always eager to find the "what," the "how," and the "why" of things. Scientists are "living question marks." They are always studying the world in which they live, and they are constantly discovering things that they want explained.

WHAT KINDS OF PROBLEMS DO SCIENTISTS SOLVE ABOUT CONDITIONS ON THE EARTH? For thousands of years men and women knew very little about the world. But as time went on, they began to study it more and more carefully. They knew that changes are always taking place in the earth and in the air around the earth. They knew that some days are cold, some are hot, some are rainy, and some are clear. And during the year the weather changes with the seasons. Men began to wonder what caused these changing *conditions* in weather and climate. They also wondered about the condition of the earth's surface. They wanted to know what made the mountains and the valleys and the plains. Why is the earth what it is, and why do conditions on earth change? What makes earthquakes and volcanoes? What about the sun, the moon, the stars, and other heavenly bodies? What are they made of, what is happening to them, and how do they make conditions change on the earth?

These were big and important questions that people were asking, and the men and women who were most eager to find the answers and who devoted their lives to study, observation, and experiment became scientists. These scientists have discovered countless facts, and they are discovering new facts almost every day. In your science study this year you will discover many of the things that they have discovered, and in the years to come you will learn more about these discoveries in books, magazines, and newspapers. Perhaps you will some day be a scientist, searching for the truth about the world in which we live.

*Self-Testing Exercises.* 1. Explain what is meant by a problem.

2. Give three examples of everyday problems that you often have to solve.

3. Explain the difference between the way Aristotle decided what is true and the way Galileo decided what is true.

4. State two interesting problems about the conditions on the earth that a scientist might be able to solve. Be sure to write them in the form of questions.

WHAT KINDS OF PROBLEMS DO SCIENTISTS SOLVE ABOUT THE MATERIALS OF THE EARTH? Fortunately for us, this world we live in gives us countless materials for making things. You are surrounded with them as you read this book. Every day you use

FIG. 4. In some of the great museums you will find scenes like this. They show what scientists have learned about how people lived on earth thousands of years ago. This picture shows two cavemen making crude tools and weapons. They used only the natural materials around them. Stones were hammers to chip off other stones for knives and axe heads. Branches of trees made the handles for stone clubs, axes, and other tools. (Chicago Natural History Museum photo)

iron, wood, rubber, wool, sugar, lead, water, cotton, glass, and many other things. The world is a rich storehouse of materials.

How long do you suppose it would take you to make a list of all the different materials that scientists have discovered and named? If you wrote at the rate of ten materials a minute for eight hours a day, it would take you about two months to finish the job. There are over 300,000 materials that differ from each other in one or more ways. Most of them you have never even heard of. All these materials come from this earth on which we live. Some of them we use just as they are found in nature. We call these *raw materials* or *natural materials*. Others we make by putting raw materials together or by taking them apart.

When men first appeared on earth, the earth was full of all the natural materials that are in it and on it today. If men had known how to discover and use them, they could have had everything that we have. But they did not know how. Of all the thousands of materials that nature provided them, they used only a few. The other materials lay in and on the earth waiting for the time when men should learn to discover and use them.

For thousands of years the discoveries that man made about

the materials of the earth were accidental. Men learned what they could by "hit-or-miss" methods. For example, one kind of iron, as it is found in the earth, looks like red dirt. No one would guess that it contained iron. Perhaps someone built a fire on this kind of red earth and in stirring through the ashes discovered some strange-looking lumps. This probably happened many times before some man was smart enough to discover that these lumps could be pounded into different shapes to make tools and weapons.

There are four important things that the scientist does with materials: (1) He discovers new materials. (2) He studies materials to find out what they are made of. (3) He finds out how to take materials apart so that he can get two or three or more materials from one kind of material. (4) He experiments with putting materials together to make new and different materials. Now let us see just what we mean by these four things.

For hundreds and hundreds of years mothers probably scolded their children for getting dirty with a certain kind of sticky brown clay. Undoubtedly the children had great fun making mud pies, balls, and perhaps even dishes from this clay. As the mothers washed the dirty hands and faces of the children, they never dreamed that some day other mothers would be cooking food in pots and pans made from a valuable material in that clay. The material was *aluminum*. There were tons and tons of it in the clay. But no one had ever heard of aluminum. No one knew that there was aluminum in the clay. It was only about a hundred years ago that scientists discovered the material and worked out a way of getting it from the clay.

Let us take another example. For hundreds of years men and women burned coal for heat. To these men and women a lump of coal was only a black stone that made hotter and better fire than wood. Then men began to learn how to be scientists—to think, study, and experiment the way scientists do. They went to work studying this black stone. They crushed it, heated it, and did all sorts of things to it to find out what is was made of. And what do you suppose was the result? They found that this black rock-like stuff was made of many different materials—materials that they could use in hundreds of ways.

Believe it or not, from black coal there are made over one thousand different dyes for coloring. The red color in the "hot dog" you eat and the yellow of the butter probably were made from materials found in coal. The soda "pop" you drink is colored with dyes made from materials in coal. When the dentist puts something into your jaw to keep your tooth from hurting while he drills it, he is using a substance made from coal. Even perfume and cloth are made from materials found in coal!

Your own home is a good example of what scientists do with materials. Just imagine what a cave-man would think if he could see a modern home. He would be amazed at the smooth, nicely shaped stone that makes the foundation. He would wonder how men ever cut and handled such an enormous rock. You would have to tell him that men took some materials from the earth, mixed them together, heated them, and made cement. Then they mixed the cement with gravel and small stones, added water, and made concrete. The concrete hardened into a single piece of artificial stone. The cave-man would never be able to understand window glass. But you would tell him that it was sand and other materials mixed and melted together and allowed to cool and harden. He would think he recognized some leather, perhaps, on a chair or a book cover. But you would tell him that it never came from the skin of an animal. It was artificial leather. Your caveman would find it hard to understand how we got all these strange materials.

FIG. 5. From black lumps of coal come the materials for many perfumes.

We could go on for pages and pages telling of the wonderful discoveries scientists have made and are making with the materials of this world. Paint, varnish, paper, Bakelite, linoleum, cloth made from wood, nylon, and steel that will not rust are only a few samples. As you study science, you will learn of many more materials, and you will find

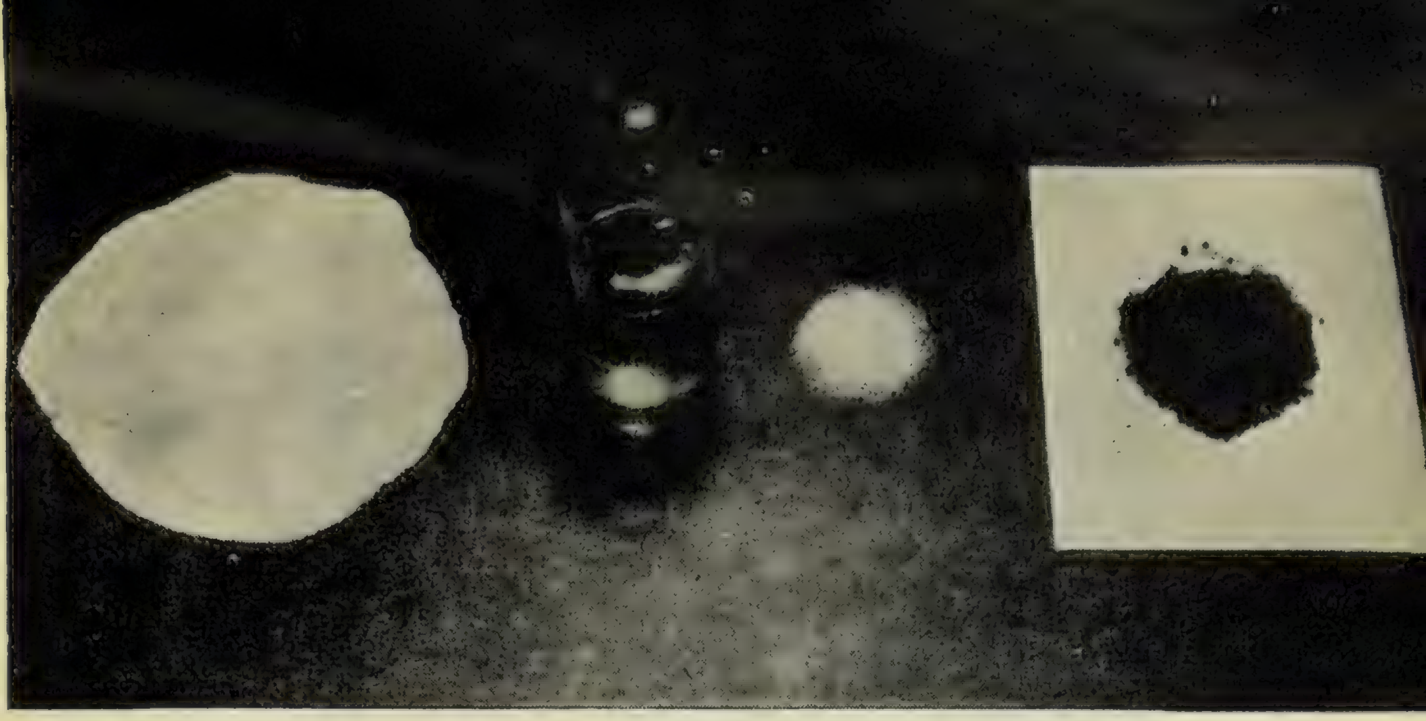

Fig. 6. Chemists can put these materials together to make plastics and synthetic rubber. From left to right the materials are limestone, water, salt, and lampblack. (INS photo)

out how they are made. Men and women who spend their lives studying what materials are made of, how materials can be taken apart, and how they can be put together are called *chemists.* *Chemistry* is the science, or knowledge, of how the materials of the world are made. In Units 2 and 3 of this book you will learn things that will help you understand how scientists work with the materials that are found in our world. You will see how they can make perfumes from coal and cloth from wood.

*Self-Testing Exercises.* 1. What four things do scientists do with materials?

2. Why do we have more materials today than men had five or ten thousand years ago?

3. Make a table like the one below. In each column write as many materials as you can. Write an N after each material that is used as it is found in the earth, for example, limestone. Write an M after each manufactured material, for example, brass.

Classification of Materials

| BUILDING MATERIALS | FUELS | CLOTHING MATERIALS | CHEMICALS | MISCEL-LANEOUS |
|---|---|---|---|---|
| | | | | |

4. Write a sentence or two that will define or explain each of these words or phrases: *chemistry, natural materials.*

WHAT KINDS OF PROBLEMS HAVE SCIENTISTS SOLVED ABOUT THE FORCES THAT WE USE? So far in this unit you have learned many things to help you understand what kind of world you live in. You have been reading about the conditions, the materials, and the living things that surround you. There is another very important thing to study in your surroundings. You live in a world of moving things—moving air, water, automobiles, trains, aeroplanes. You yourself, or parts of you, are always moving. But nothing in this world moves unless it is pulled or pushed by some kind of *force*. We live in a world of forces. You can quickly realize how important they are if you try to imagine a world in which nothing moves. Let us then learn first about the greatest force of all.

FIG. 7. The force of gravity is bringing the parachute jumpers back to earth again. (Acme photo)

Everything is held to this whirling, spinning earth by a mysterious force called *gravity*. No one knows just what gravity is. But you know that if you step from an aeroplane in mid-air, you will fall to the earth. The force of gravity keeps you from falling off the earth as it whirls around through space. It is the force of gravity that brings a baseball down when the ball is thrown into the air. "All that goes up must come down on somebody's head or crown" is no joke. Aeroplanes may rise against the force of gravity if their engines produce enough force, but if the propeller stops turning, down they will come. There is no getting away from the force of gravity. We may not know what gravity is, but scientists have discovered some amazing things about how it works.

You have seen another effect of the pull of gravity when you have watched a moving stream. What do you suppose makes the water flow in the direction it does? Water is a liquid and

is free to move in any direction, as you have discovered when you spilled a glass of water on the table. Gravity pulls on it, just as it does on everything else. Since water is free to move, it flows from higher places to lower places. Primitive man used the force of gravity when he travelled downstream on a floating log. Since those days scientists have solved many problems so that we can use the force of moving water to work for us.

On your way to and from school you may have had an unpleasant experience with gravity. A sudden gust of wind may have blown off your hat and sent it sailing down the street. Perhaps you wonder why we blame gravity for this happening. That is one of the important things you will learn in your study of science.

There are, however, other powerful forces in the world. One of these is steam. Steam was known as far back as 2000 years ago. A Greek by the name of Hero developed an engine that was driven by steam, but no practical use was ever made of it. Seventeen hundred years later, however, men in England were at their wits' end to keep water out of a coal mine. They could not work the pumps fast enough. Even the horses that they sometimes used for power could not make the pumps work fast enough. Here was a job in which the force of the muscles of men and of animals would not do. So men experimented with steam, and they invented an engine that used the force of steam to make it run. These steam engines worked the pumps fast enough to keep the water out of the mines. Since those days scientists have been able to make steam engines much more powerful because they have learned more about metals and more about how to control fire and heat.

For a long time the steam engine supplied most of the power in places where there was no moving water for power. But men were experimenting with electricity. From the beginning of time there had been electricity in nature ready for man to use. Man saw it in the lightning. But he did not know how to make it useful. About 150 years ago Alessandro Volta, an Italian scientist, invented the electric cell. This, however, would not produce electricity in large quantities. But it started scientists to thinking about and experimenting with electricity. After about fifty

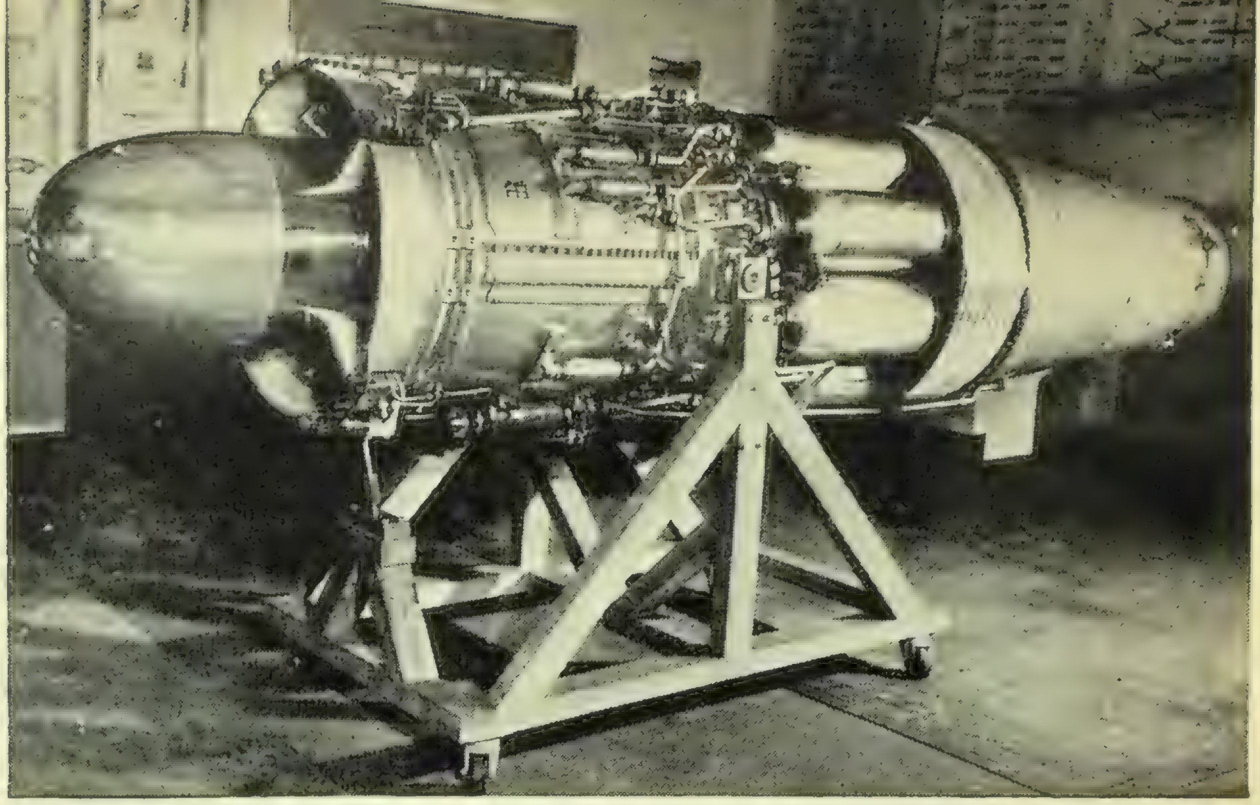

FIG. 8. This jet-propulsion engine uses no whirling propeller to drive an aeroplane faster than 500 miles an hour. Air rushing in at the front is compressed and mixed with kerosene. The mixture burns in a continuous explosion, which gives the force that drives the engine forward. (General Electric photo)

years scientists invented a machine that could make large quantities of electricity. This machine used the force of moving water and the force of steam to make electricity. Today electricity runs street cars, helps make automobiles move, lights our homes, cooks our food, and does many other things for us.

About fifty or sixty years ago inventors gave the world another important power machine. This was the gasoline engine. Man had learned how to make gasoline from the oil he found in the earth. Then he had learned that gasoline could be made to change into a gas that would explode with terrific force. The next thing was to invent an engine that could use the force of the exploding gas. You know that men did invent such an engine. We use this engine to run our automobiles, our aeroplanes, and many other kinds of machines.

Now you have learned the most important forces that man uses to do his work. There are other forces about which you will learn, but these are the important ones. So long as men had to do all of their work with their own strength, they could make little progress. There was more work to be done than they could do. But the forces of nature have multiplied man's own force. Scientists have discovered and harnessed these forces of nature

for us. Because they have done so, we live very differently from the people of even one hundred years ago.

*Self-Testing Exercises.* 1. Write a story telling what the world would be like if all forces stopped.

2. What three forces did man use thousands of years ago?

3. What three forces had to be discovered by scientists?

4. What force makes rivers run to the ocean? Give two ways you use that same force.

5. One of the machines in common use is the pile-driver. A heavy weight is lifted and then let fall upon a pole that is to be driven into the ground. What force is being used?

6. Make a table like the one below. In each column name machines that you have seen operated by the power machine named at the top of the column, as shown under "Water-wheel."

Kinds of Machines

| WATER-WHEEL | WINDMILL | STEAM ENGINE | ELECTRIC MOTOR | GASOLINE ENGINE |
|---|---|---|---|---|
| Dynamo<br>Sawmill | | | | |

WHAT ARE SOME PROBLEMS ABOUT LIVING THINGS? So far you have learned something of the conditions and the materials of the world we live in. But conditions and materials are not all that make our world the kind of world it is. Let us get a big picture of another part of our surroundings. We live in a world of living things—plants and animals.

If you were asked to guess how many different kinds of animals there are, what would you say? Probably you have seen only a few hundred kinds. Scientists, however, have found and named over 800,000 different kinds of animals. Each of these kinds of animals differs in some ways from all other kinds. You would probably be far wrong in your guess as to the number of different kinds of plants. At the present time over 225,000 different kinds of plants have been discovered and named.

Very early in his life on this earth man probably thought of all living things as either friends or enemies. Animals and plants that did not harm him and that furnished him with food or clothing were his friends. Animals that tried to kill or injure

Fig. 9. Man has learned many ways of protecting his food plants from disease and insects. In this picture fruit trees are being sprayed with poison to kill insects. (Caterpillar Tractor Co. photo)

him were enemies. Plants that made him sick or tore his skin with thorns were enemies, too. Of course, man tried to preserve his friends and destroy his enemies among living things. He had to do this, because the friendly living things provided him with all his food and his clothing.

But man was not satisfied with the plants and animals that he found in nature. He began to try to improve the ones that were useful to him. Scientists have done just as wonderful things with plants and animals as they have with coal and other materials. Wild plums are not much bigger than marbles. But the scientist learned how to make them grow into the large juicy plums we now have. Wild horses were little fellows that you would call ponies. From these small wild horses man has developed the beautiful, powerful horses that haul great loads and do other work for us. Grapefruit never grew wild in nature. But from plants that nature did provide, man learned how to grow a grapefruit plant. One famous experimenter even grew a plant that produced white blackberries.

Scientists had to make many discoveries and solve many problems before they could improve plants and animals. They had to learn how living things grow, what kinds of food are best for them, and how much light and heat and moisture plants need. Plants and animals get sick; so scientists have studied the diseases of plants and animals and have learned how to cure many of them.

Throughout the world today thousands of scientists are studying our living neighbors, finding how to use and improve the helpful ones and how to destroy the harmful ones. The scientists who study living things are called *biologists*. *Biology* is the science or knowledge of living things. Every year biologists are finding ways of growing more useful plants and animals. But there are still plenty of problems for the biologists to solve. Perhaps some day you will be helping solve these problems.

*Self-Testing Exercises.* 1. List ten kinds of plants and ten kinds of animals found near your home. From all the lists in the class make a big list of plants and a big list of animals. Label it "Our Living Neighbors."

2. State five problems that men had to solve before they could improve plants. Your first problem might be, "How do plants grow?"

3. List five ways man has made living things better for his needs.

4. What is a *biologist?*

WHAT KINDS OF PROBLEMS DO SCIENTISTS SOLVE ABOUT YOU? When you have completed your study of this book, you will know more about how you are put together and about the things that make you well or sick than the wisest scientist a hundred years ago knew. A hundred years ago no one knew anything about germs and how they caused disease. Since people did not even know about germs, there were no methods of preventing disease. If people were strong, they got well; otherwise they died. Today we know the particular kinds of germs that cause certain diseases. As yet, the causes of many diseases are unknown, but thousands of scientists all over the world are working on problems connected with disease. Every year a little knowledge is added to what we already know. In your lifetime you may see the conquest of disease achieved.

To solve problems about disease, scientists had to study the human body to see how it was put together. They had to discover how the various organs of the body worked. We now know what happens when we breathe, how the blood is forced around the body, how food is digested so that it can be used by the body, how broken bones grow together again, how our muscles work, how we see, feel, hear, and smell, and many other things concerning what is happening in our bodies. Some of

FIG. 10. Thousands of people owe their lives to this great British scientist, Sir Alexander Fleming. Working in his laboratory, he discovered the powerful germ-killing drug called *penicillin*, which is made by a tiny mold plant. (British Official photo)

these things are known to you, but it has taken man thousands of years to learn about them.

Another problem that scientists have worked upon and are still working on is the problem of our food. Scientists know just what substances our bodies are made of and just what foods are needed to make us grow and keep us in a healthy condition. Only recently have they found that there are some substances called *vitamins*, which are present in certain of our foods. They have also learned that if our bodies do not get enough of these vitamins, we become ill with certain diseases. Today there is no excuse for not knowing the proper foods to eat. This is one problem that scientists have practically solved.

Other problems upon which scientists are working deal with ways of taking care of the body, or personal *hygiene*. How to use your eyes, how to develop strong muscles, how to keep clean, how to develop a correct posture, how to dress properly in different kinds of weather—these are but a few of the problems which have been solved to help you keep healthy.

When people gathered together and built large cities, many problems were raised concerning a proper water supply, a safe food supply, disposal of garbage and human wastes, keeping the city clean, and preventing the spread of disease. Most of these problems are related to *sanitation*. To see what progress scien-

tists have made in solving these problems, you have only to remember the great plagues which swept our cities a hundred or more years ago and caused the death of thousands of people.

But with all the inventions and discoveries man has made, he has never conquered nature. He must obey the rules, or laws, of nature. You can quickly see that man cannot do exactly as he pleases. Think of the care you must take of your body if you wish it to work well. For example, you may decide that sleeping is a waste of time. You may decide this, but nature has decided differently. After a time you will fall asleep no matter how hard you try to stay awake. You may like candy so well that you decide to eat only candy for your meals. You know what will happen.

Now you see what many of the problems are that scientists have solved and are solving about the world we live in. You have also begun to understand how the work of the scientist has helped man. We use our knowledge to change the world, but we also use it to help ourselves fit better into nature's way of doing things.

*Self-Testing Exercises.* 1. What are some of the things that man has learned to do in order to keep his health?

2. Is it correct to say that man has conquered nature? Explain.

## 2. How do scientists solve problems?

YOU HAVE BEEN READING about the kinds of problems that scientists solve. Now let us see how scientists solve them. You will need to know how a scientist thinks and works, because you will soon be solving some problems yourself. We shall first take a very simple problem and see how a scientific thinker would solve it.

Your best kite, one that flew perfectly, caught in a tree while you were pulling it down. Your problem is how to get it out of the tree. A number of ways of solving the problem come to your mind. Before doing anything about it, you think over these different ways and try to decide upon the best method to use. You decide that if you pull on the string, you will tear or break the kite. You are also sure that throwing sticks at it may tear the paper. So you give up these two methods without trying them.

There is a ladder in the garage at home, and you know just about how high the ladder will reach. Careful study of the distance from the ground to the kite shows you that the ladder is not long enough. You give that idea up, too. You think of climbing the tree. But the kite is out on the end of a limb, and you decide that the limb will not hold you up.

However, you see a big limb just above the one where the kite is. You decide that you can hold on to the upper limb and work your way out almost to your kite. Then perhaps you can shake the limb enough to jar the kite loose. This seems to be the best plan of all; so you decide to try it. You do try it, and it works. You have solved your problem.

Now perhaps you are wondering why this is an example of good thinking. Let us see the steps you used in thinking out your problem. In the first place, you knew exactly what it was you were trying to do. In other words, you had clearly in your mind just what the problem was. Of course, in this simple example the problem was easy to see. But many times it is very hard to know exactly what you are trying to find out. Until you know just what it is you are trying to find out, you cannot go on with your thinking and experimenting.

Then you began to think of ways to solve your problem. A poor thinker very often fails at this point. He takes the first plan that comes to his mind and tries it out. If this plan does not work he tries the next thing he thinks of, and so on. At last he either solves his problem or runs out of ideas. He wastes much time and may get himself into trouble. A good thinker does not work this way. He thinks of a number of possible ways of solving his problem. Instead of actually trying each plan as he happens to think of it, he studies each plan carefully to see if it is likely to work. He sees that some of the plans are not good; therefore he gives them up.

Finally the good thinker chooses a method that he believes will work. He then tries this method to see if it is the correct way to solve his problem. In other words, he experiments to discover whether or not his idea is correct. Experimenting is a way of testing our ideas. All scientists test their ideas by experiments before they are sure the ideas are true.

FIG. 11. Science has solved many problems to help us grow the plants we need for food. Growing corn on the same land every year cut the crop down to only twenty-three bushels per acre, shown at the right. But the land produced almost twice as many bushels per acre, shown at the left, when the crops were changed every year.

Now let us take a problem in science to see just how a scientist thinks and works. Farmers used to raise the same crops year after year on the same land. Finally they noticed that their crops were getting poorer each year. They did not know why. They planted the seeds in the same way, but fewer of the seeds grew into good plants. This was a problem for a scientist. The scientist first thought of all the things that might keep the plants from growing. The poor crops might be caused by bad weather for a period of years. But the records of the weather bureau showed that the weather had not been unusually bad. Further investigation showed that when farmers used land where no crops had grown, the plants would grow very well for awhile; then after a few years the crop would again begin to fail.

Now the scientist knew that plants use certain minerals from the soil when they grow. He had learned this by finding out just what materials the plants were made of. So he thought, "Perhaps the plants have used up the minerals in the soil, and that is why they won't grow." This seemed to be a good idea, but of course it had to be proved. How could it be proved? If crops took minerals from the soil, there would be a difference between soil that had been used and soil that had not been used to grow crops. This idea could easily be tested. The scientist took a sample of soil that had been used and a sample of soil

that had not been used. He tested these two kinds of soil to find what minerals were in them. He found that there was a difference. The unused soil had more of the minerals that plants need than the other soil had. The scientist seemed to be on the right track. But he still had not proved that the cause of the poor crops was the lack of minerals in the soil. How could he prove this?

If the cause of poor crops was the lack of certain minerals, then the plants should grow better if these minerals were put in the soil. This sounded like good thinking, but the scientist could not be sure it was right just because it seemed to be a good idea. He had to experiment to test his idea. So he added the minerals to the soil, planted some seeds, and waited for the harvest. The result was just what he thought it would be. The plants grew well and produced a good crop. Now he was ready to believe that his idea was true. He had proved that the crops had failed because certain minerals were absent from the soil, and that crops would grow again if these minerals were added to the soil. This is the idea we use when we put fertilizers on soil to make it richer.

Now let us summarize what we have learned about the way the scientist thinks and works.

1. The scientist gets clearly in mind the problem he wants to solve. He sees clearly just what it is he is trying to do, or explain, or prove, or disprove.

2. He thinks of all the possible ways of explaining the facts he has found, or of solving his problem.

3. He chooses the explanation, or solution, that looks as if it might be the correct one.

4. He plans and tries an experiment to see if his explanation, or solution, is the correct one.

5. If the experiment seems to show that the explanation is a good one, he tests the explanation by other experiments to be sure that the solution is correct.

Scientists always *verify*, or prove, their results. Usually, when a scientist announces a discovery, he tells how he did the experiment and how he verified, or proved, his discovery. He does just what you do when someone says, "Well, how do you know

it is true?" Other scientists test his results by repeating his experiments and by working out new experiments to prove his idea right or wrong. A good scientist will never announce a discovery to the world until he has tested its truth in every way that he can.


FIG. 12. Farmers can take samples of soil from their farms to be tested by trained scientists.

*Self-Testing Exercises.* 1. Close your book and make a list of the five steps scientists use in solving a problem. If you cannot remember them all, study until you can write them from memory.

2. What does the word *verify* mean?

3. Why are the discoveries that are announced by scientists likely to be true?

4. Give one important reason to show why scientists perform experiments.

5. Make a list of ways in which a poor thinker might get the wrong answer to his problem or might take much longer than necessary to get the right answer.

6. On a full-size sheet of paper make a table like the one below. Use plenty of room so that you can put in all the five steps instead of just the first two. Then fill in the entire table. Do as much as you can from memory.

| STEPS IN SOLVING A PROBLEM SCIENTIFICALLY | EXAMPLE OF KITE IN TREE (pp. 19-20) | EXAMPLE OF CROPS THAT DID NOT GROW WELL (pp. 21-22) |
|---|---|---|
| (1) Decide exactly what the problem is. | To get the kite down without tearing it. | To find why plants do not grow well in the same field year after year. |
| (2) Think of all possible solutions. | Pull on string. Throw sticks, etc. | |

*Problems to Solve.* 1. Suppose you baked a cake, and it did not turn out well. What problem would this raise in your mind? How might you go about solving it?

2. John made a model aeroplane. When he attempted to fly it, he found that it would not rise from the ground. How could John go about solving the problem?

3. Many people believe that toads cause warts. How would you prove whether or not this is true?

4. Take some problem of your own and tell how you would solve it, using the scientific method.

## 3. How have scientific instruments helped scientists solve problems?

When we read of some of the things that people believed a few hundred years ago, we wonder how they could have believed them. You and all the others in your class know that the earth is ball-shaped and that it moves around the sun. Yet there was a time when the wisest men believed that the earth was flat and that all the heavenly bodies moved around the earth as a centre. You know that frogs hatch from tiny eggs laid by the mother frog. But not so long ago men believed that frogs grew from the mud at the bottom of rivers and ponds. Two thousand years ago the wisest men thought that everything on the earth was made of four things: air, water, soil, and fire.

But we must remember that scientists today have many helpers that scientists of a few hundred years ago did not have. These helpers are the marvellous instruments that men have invented. With these instruments men can weigh and measure and see and hear as they never were able to do before. Let us see how some of these instruments have helped solve problems.

About 2200 years ago a man named Aristarchus told some of his friends that he thought the earth travelled around the sun. But no one believed he was right. About 1800 years later another wise man and careful thinker, named Copernicus, came to believe as Aristarchus did. But still only a few thoughtful people here and there were willing to believe it. Almost everyone was sure the sun moved around the earth. But Galileo, about whom you read earlier in the unit, believed Aristarchus. Now, what these daring thinkers needed was some way of proving the truth of what they believed. They needed something that people could actually see with their own eyes; then, perhaps, people would believe what the scientists had discovered.

One day Galileo, in Italy, heard that Johannes Lippershey, a spectacle-maker living in Holland, had invented a very

interesting toy. When you looked through the glasses in this toy, things that were far away seemed to be near at hand. Lippershey had invented the *telescope*, although he did not understand what a wonderful thing he had done. Galileo immediately started to make a telescope for himself. The first telescope he made would magnify three times, but finally he made one that would magnify thirty times. Then he turned this telescope on the heavens and saw things that no human being had ever seen before.

FIG. 13. From the top of a tower in Venice, Galileo is showing some of his friends what wonderful things the telescope does. (Bausch & Lomb photo)

One night, as he was studying the stars and planets, he noticed what appeared to be three little stars near the planet Jupiter. One star was on the right, and two were on the left. On another night he was surprised to find all three of the stars on the right. On still another night there were four of these little stars, three at the right, and one at the left. At first he believed his eyes were fooling him, but more watching made him sure that the little stars were travelling around Jupiter.

Now of course this did not prove that the earth travels around the sun. But it showed that some of the heavenly bodies were revolving around Jupiter instead of around the earth. Therefore, the earth could not be the centre of everything. With their own eyes men were now able to see that up in the vast spaces of the heavens things were different from what people had thought. Without the telescope we would believe that we see all of the

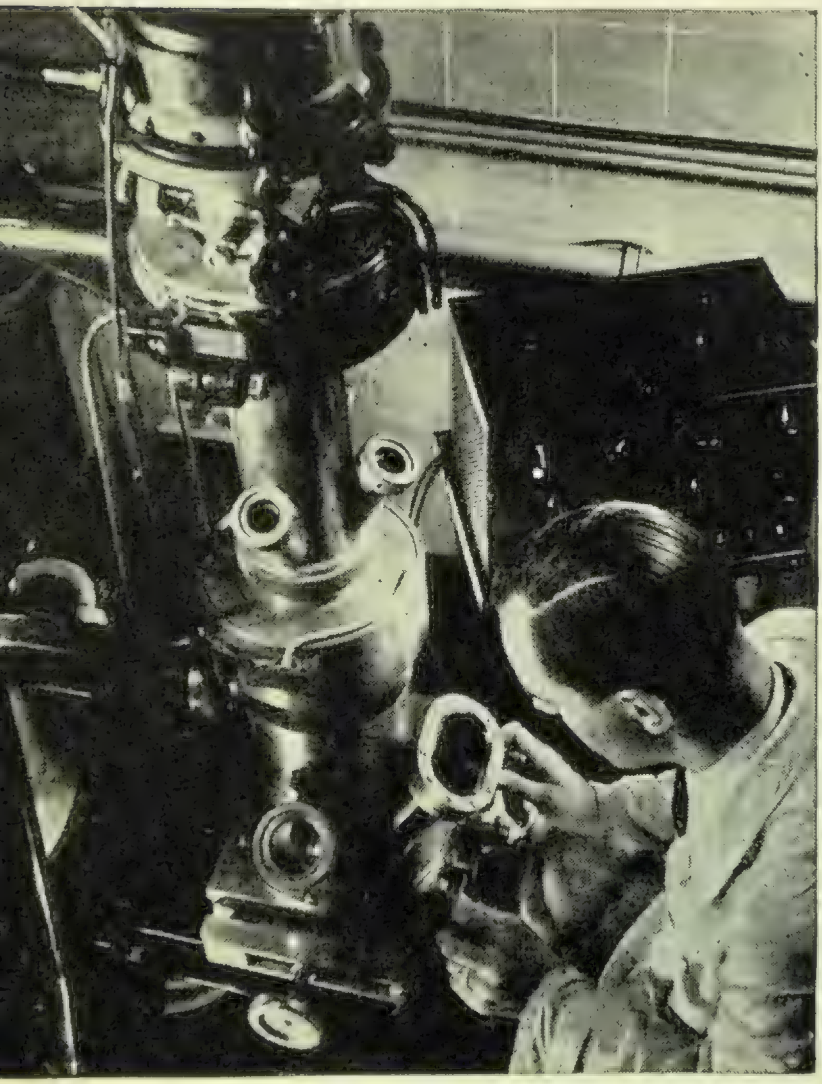

FIG. 14. Using the new electron microscope that magnifies objects 100,000 times, this scientist is studying germs that cannot be seen with an ordinary microscope. (Black Star photo)

stars there are. But the telescope shows us that we cannot always trust our eyes.

About three hundred years ago another scientific instrument was invented which, like the telescope, showed us how little we can really see. This instrument was the compound *microscope*. It was invented by a Dutchman, named Zacharias Janssen. For a long time almost no one ever used the microscope seriously, although a few scientists found it helpful in looking at insects. Of course the first microscope was a poorly made instrument. It would not show what our wonderful microscope of today will show. But it is hard to understand why it took men two hundred years to realize how important the instrument was in solving important problems.

Imagine, if you can, the thrill that must have come to the scientist who first examined a drop of water and found it swarming with tiny animals. These animals were so small that they had to be magnified hundreds of times before they could be seen. This was one of the greatest discoveries ever made. It started scientists on discoveries which proved that many kinds of disease are caused by tiny plants or animals invisible to the naked eye. Once more the invention of a scientific instrument helped solve problems that had been puzzling scientists for thousands of years. Another instrument of great service in scientific discovery is

the *analytical balance*. This is really nothing more than an extremely delicate pair of scales for weighing things. Some balances are so delicate that they will weigh the pencil marks you make when you write your name. The analytical balance has made possible many of the great discoveries about the materials of which things are made.

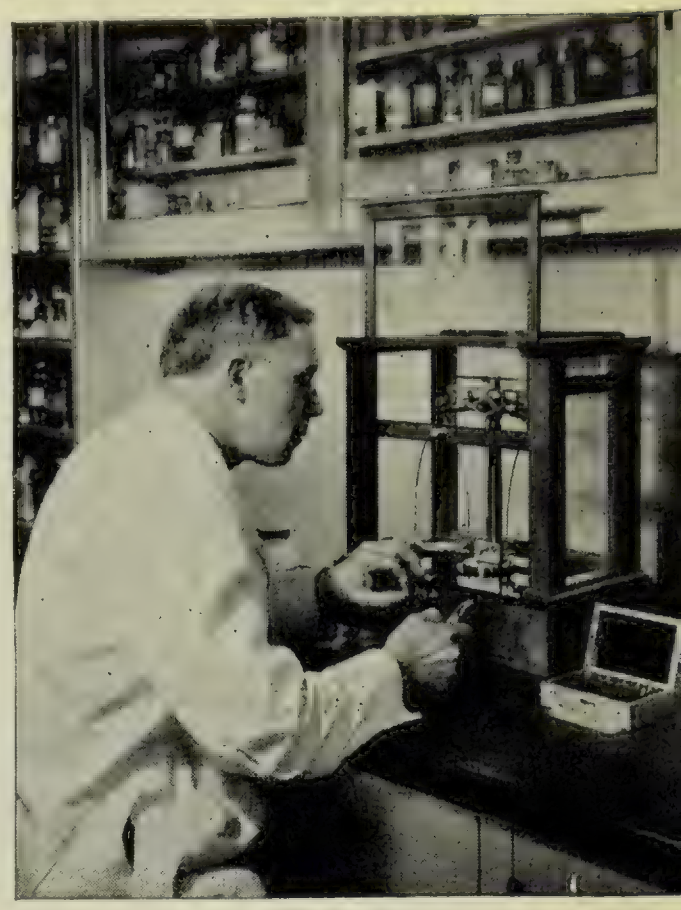

FIG. 15. This scientist is using an analytical balance. Notice how carefully he is handling the balance. In science work things must be measured exactly.

An even more sensitive instrument is the *spectroscope*. How the spectroscope works is too difficult to explain here. But by its use scientists have been able to discover the kinds of substances of which the sun is made. When you remember that the sun is over 90,000,000 miles away, you can well imagine how sensitive this instrument must be. The spectroscope and the telescope have told us most of what we know about the heavenly bodies. One interesting example of the use of the spectroscope was the discovery of a material that had never been known to exist. A scientist, studying the sun one day with a spectroscope, found in the sun a strange material. It was unknown on earth. He named it *helium*, which means "sun element." Thirty years later another scientist was examining with the spectroscope a mineral that is common on the earth. He discovered helium in it. Later, helium gas was discovered in large quantities in a few places in the earth. Now it is used to fill dirigible balloons.

We use one of the instruments of science ourselves when we read the *thermometer* to tell temperature. However, most of the common thermometers are quite inaccurate. If they measure within a degree or two of the correct temperature, they are accurate enough for our everyday uses. But the thermometers used by the scientist are much more accurate and delicate than the ones we use every day. Some of them are so sensitive that

FIG. 16. Joseph Fraunhofer, a German, invented the spectroscope about 150 years ago. In this picture he is showing one of his friends how the spectroscope works. (Bausch & Lomb photo)

they can measure the heating effect of candles placed several miles away. They will even show a change in temperature if one of the candles goes out. Such thermometers are used largely to find out the temperatures of distant stars and planets.

In the field of medicine scientific instruments are of the greatest value. The modern doctor listens to the beat of the heart with the *stethoscope*. This instrument also tells him important things about the condition of the lungs. He takes the body temperature with a *clinical thermometer*. He examines the organs and bones in the body by means of the *X-ray*. Under the microscope he examines blood to determine its condition and makes many other tests of the body. With these instruments he is often able to discover what is making the patient ill. When he understands what the disease is, he can work out ways of fighting it.

In spite of all that science has done for us, many people even today do not believe what scientists tell them. They believe only their own eyes and ears. They do not like to give up ideas they have believed for a long time. But you have learned that our eyes and ears do not always tell us the truth about what we see and hear. A glass of water to the naked eye may appear perfectly pure. But a scientific experiment may show that it is full of disease germs. In your study of science you may find many things that are hard to believe. Remember, however, that science is tested knowledge.

However, you will sometimes hear or read of things that are said to be proved by experiments. Many times such things are

not true because the experiments were not reliable. A good knowledge of science will help you tell the difference between true science and false science.

*Self-Testing Exercises.* 1. Why can the modern scientist discover more facts about the world than scientists of long ago could discover?

2. How does each of the following instruments help the scientist? Telescope, microscope, analytical balance, spectroscope, thermometer, stethoscope, X-ray.

3. Suppose a scientist writes an exact description of something. You look at the thing described, but it does not look that way to you. Who is more likely to be correct, you or the scientist? Why?

*Problems to Solve.* 1. Describe some ways in which a motion-picture camera might help the scientist solve his problems.

2. What instruments have you used to help you see, hear, weigh, and measure?

3. Describe the instruments that you have seen a physician use. What did he learn by the use of each instrument?

4. If you have had your eyes tested, tell what the doctor did to find out what kind of glasses you needed.

5. Look at some object with your naked eye; then look at it through a microscope or a reading glass. What did the instrument show you that you could not see without it?

## Looking Back at Unit 1

Write a one-page theme that answers the problem of this unit—How Do Scientists Work? Be sure to include all of the most important ideas you have gained by reading the unit.

## Additional Exercises

1. From the reading list on page 30, choose biographies of several scientists. Read them. How did the scientists get started in scientific work? What discoveries did they make? How did they solve their problems? In what ways did their discoveries change our way of living?

2. Keep a scrap-book in which you record new inventions and discoveries. You will find articles in daily newspapers. You will also find reports of discoveries in magazines, such as *Time*, *News-Week*, *Scientific American*, *Popular Mechanics*, *Life*, and others.

3. Obtain automobile folders and list the improvements that have been made in the past year. You can make an interesting study of the development of automobiles by looking at advertisements for a period of years, noting the improvements mentioned for each year.

4. Select one of these inventions and from reference books find all you can about the inventor and how he worked out the invention: telescope, microscope, X-ray, thermometer, spectroscope.

5. Visit the county farm agent. Find out from him how he determines the kind of fertilizer that a farmer needs for his field.

6. Suppose you were going to buy a vacuum bottle. The dealer has two bottles that look very much alike, but one costs considerably more than the other. The dealer tells you the cheap one is just as good as the expensive one. How could you find out whether this is true? If you can do so, try your experiment.

7. If there is a factory near you, visit it and find what scientific instruments are used.

8. How would you find out whether the direction of the wind will tell you whether it is going to rain? Test your plan. What do you discover?

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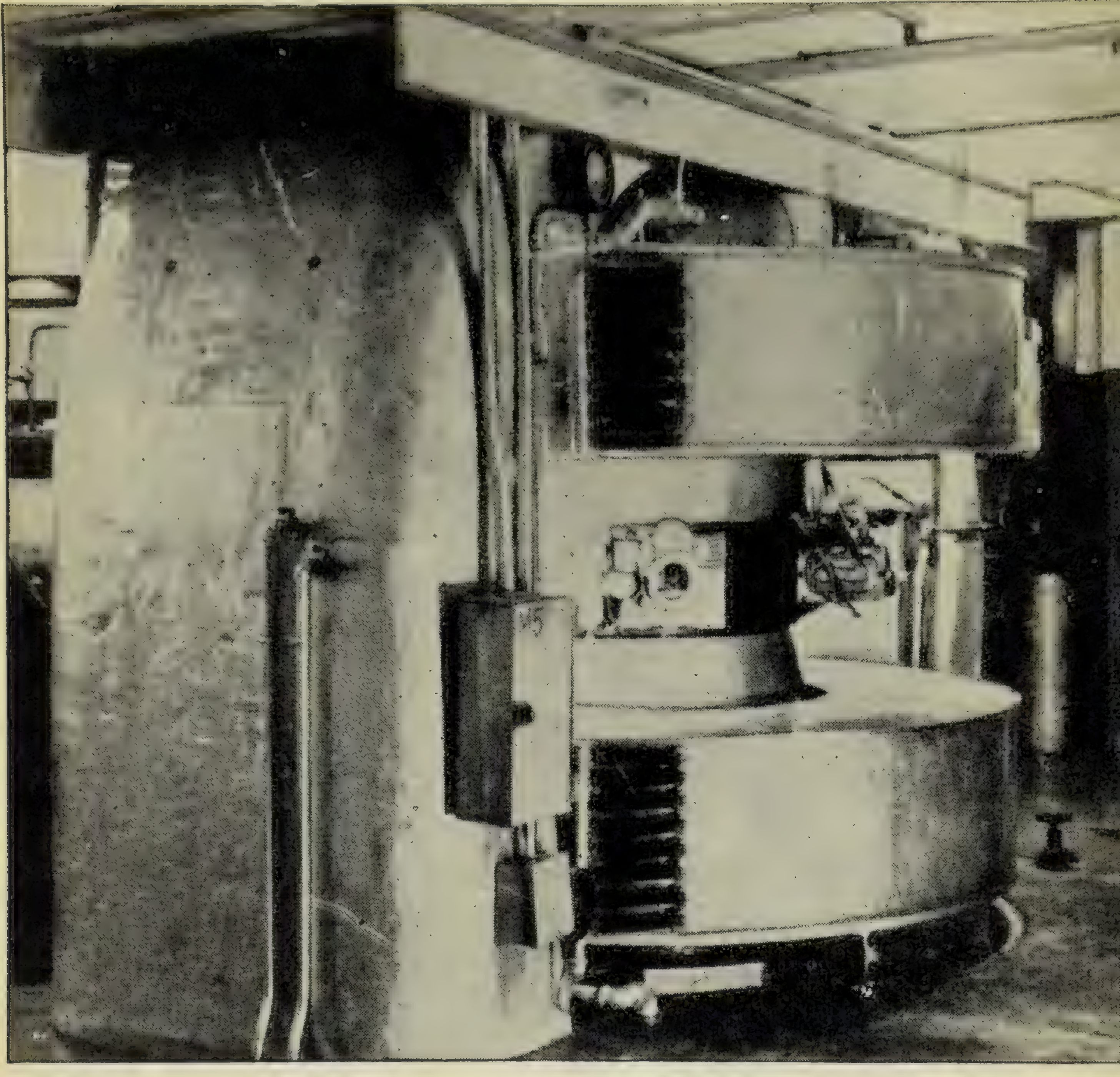


TO LEARN MORE FACTS ABOUT MATERIALS, scientists built a 10,000,000-volt "atom smasher" called a cyclotron. Its seventy-ton electromagnet whirls tiny particles of matter faster and faster until they are travelling at very high speeds. Then the speeding particles are shot out like bullets against a target made of some material to be tested. As they crash into the target with great force, the material may be changed into another material. Rays like X-rays or those from radium are usually given off, too. By studying the results of their experiments, scientists have found out many interesting things about materials. (Ewing Galloway photo)

# UNIT 2

# What Are Things Made Of?

## Looking Ahead to Unit 2

How is this book like the water that you drank this morning? How is it different from the water?

How is the water you drank like the air you breathe?

If you pump up an automobile tire, does it weigh the same that it did before you pumped it up?

How many different materials are there in the world? How many can you name?

The questions that you have just read have probably made you wonder what this unit is about. Perhaps some of the questions even seemed foolish to you. "Everybody knows," you may have said to yourself, "that a book and water are not at all alike. One is made of paper and cloth, and the other is made of—well, it is just made of water. They are not even used for the same purpose." Perhaps it seemed still more foolish to you to think that water and air are alike. So by this time you are probably wondering why you are asked all these questions that seem impossible to answer.

But, strange as it may seem, a book and water are alike in some ways. We can go even farther and say that air, too, is like a book and like water. Perhaps you cannot see why this is true. But you will see how a book, water, and air are alike when you have studied this unit.

When you have found out how materials like air, wood, and water are alike, you will not make the mistake that John did one day. The teacher placed three drinking glasses on the table. She poured water into one glass and put soil in another. She put nothing in the third glass. Then she asked John to look closely at the glasses to see if each glass was full of something. John was so sure of himself that he quickly said, "One is full

FIG. 17. Which objects in this picture are alike? Which objects are very different from some of the others?

of water, one is full of soil, but the third one is empty." Nearly everyone in the class thought that John was right. Perhaps you think so, too. But Henry did not think so. He said, "Each glass is full of something." John argued with him, but Henry stuck to what he believed. "I can prove it," he said. How do you suppose Henry proved that none of the glasses was empty?

By this time you are perhaps beginning to be puzzled. You may even be saying to yourself, "A book, air, and water are alike, and an empty glass isn't empty. Is this sense or nonsense?" But there are more puzzling things to come. Do you think it is possible to pass sugar through a handkerchief without tearing the handkerchief? Perhaps you say, "No. Sugar can't be passed through a piece of cloth." But it can be done if you know how to do it. You will see that these statements are correct when you study this unit and learn what things are made of.

And before you begin the unit, try to answer this very simple question: Why do things have weight? You have known most of your life that things weigh. Some are heavy; some are light. Why? A simple question, and a rather simple answer if you know your science. You will find the answer in this unit.

## 1. What do we mean by "materials"?

HOW ARE ALL MATERIALS ALIKE? We have said that rock, water, and air are alike. When you look at these materials, you see at once that they do not look alike. A block of stone is solid material. We say that it is a *solid*. No matter where you put it, it keeps its shape, and it stays there. If you pour water on

a table, it makes a puddle or runs off on the floor. It does not have any shape of its own. We say that water, milk, gasoline, and similar materials are *liquids*. You cannot see air at all. You cannot cut off a piece of air and put it on the table. But you know that there is air around you because you can feel it. You also fill your bicycle tires with air. Air does not have any shape of its own, and it fills up any space that it can enter. Air and other materials like it are *gases*.

So far you have seen only the ways in which air, water, and rock are different. Now how are these materials alike? If you pick up a piece of rock, you notice that it weighs something. How about water? Does it have weight, too? You do not need to experiment to discover whether water has weight. Everyone knows that a big bucket of water is heavy to carry. So far, you can easily see that water and rock are like each other in at least one way: They both have weight. It is not so easy to see that air also has weight. A handful of air does not seem to weigh anything. Of course, you would not expect such a thin material as air, or any other gas, to weigh much. Since you cannot tell whether air has weight by lifting it in your hands, you will have to discover some method of weighing it.

*Experiment* 1. DOES AIR HAVE WEIGHT? Get a football or a basketball and a balance, or pair of scales. Squeeze most of the air from the football and place it on one pan of the balance. Also place on the pan the rubber band or string or whatever is used to keep the air from leaking from the football when it is pumped up. Add weights to the other pan until the two pans are in balance. (Small pieces of paper or tin-foil may be added to get an exact balance.) Now pump the football full of air and tie it shut. Then put it back on the balance. Does the football weigh more than it did, or less? Or does it weigh the same as it did? How do you know? How do you explain what happened?

Now you are ready to believe that rock, air, and water are alike in at least one way: They all have weight. Of course, this is true of all materials. In fact, you can define a material as anything that has weight. There is still another way in which all materials are alike. Let us suppose you have a box that you are

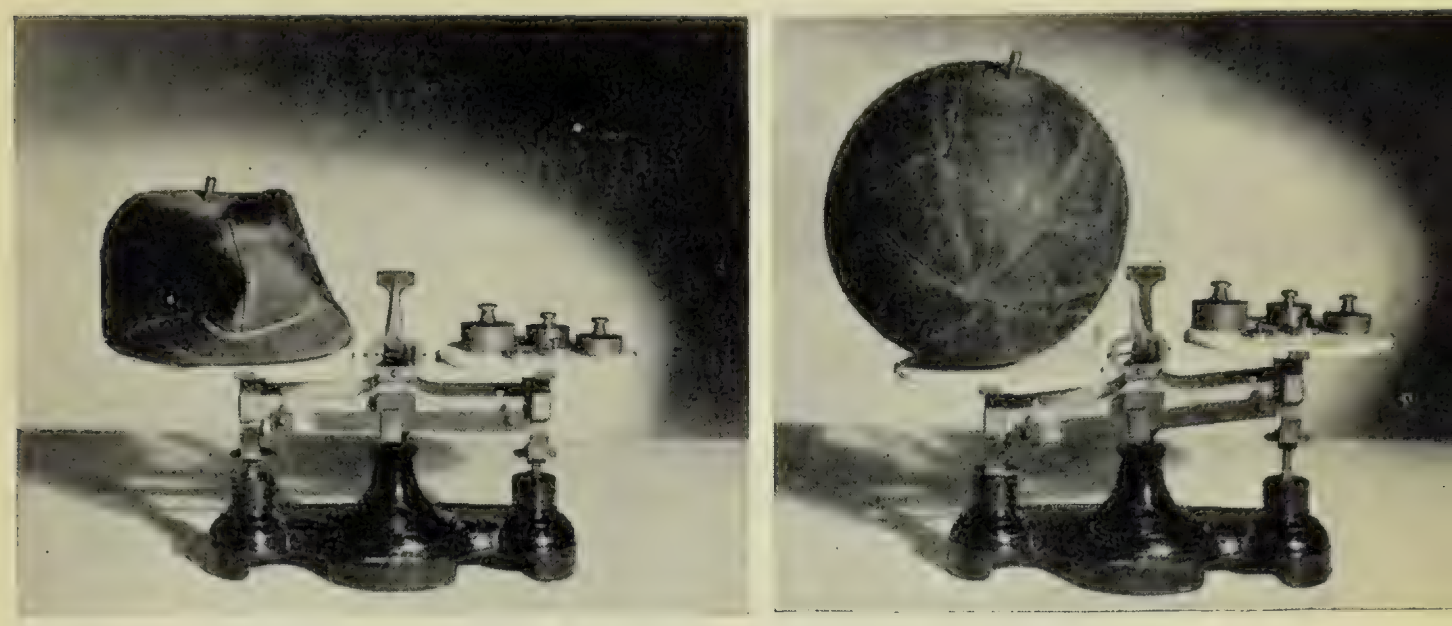

Fig. 18. Apparatus for Experiment 1

going to fill with wooden blocks. There is only a certain amount of space in the box; therefore, the box will hold only a certain number of blocks. Water also takes up space. A glass will hold only a certain amount of water. After the water has taken up all the room in the glass, no more can be added. It is easy to see that wood and water take up space, but what about air and other gases? Do they, like solids and liquids, take up space?

*Experiment* 2. DOES AIR TAKE UP SPACE? Get a large jar or pan three or four inches deep and fill it nearly full of water. Also get an ordinary drinking glass and a flat cork (or a chip of wood). Put the cork on the water. Now place the open end of the glass over the cork and push the glass downward into the water. Watch the cork in the glass. Does the water rise in the glass so that it becomes filled? What stops the water from rising in the glass? Is it correct to say that the glass is empty? How does this experiment prove that air takes up space?

*Self-Testing Exercises.* 1. In what two ways are all materials alike?

2. Tell how you did or could do an experiment to show that air has weight.

3. Tell how you could show one of your friends that air really fills space.

4. When a scientist makes a statement, he expects to be asked, "Why do you believe that?" So he is always ready to back up his statement with proof. This is a good habit for all of us to have. It is

also a good idea to ask other people to prove their statements. "How do you know?" is a good question to ask.

Do you believe or not believe that all materials take up space? Why do you believe as you do? Give several reasons.

5. Do you believe or not believe that all materials have weight? Why do you believe as you do? Give several reasons.

(*Look up the words "solid," "liquid," and "gas" in the list of Science Words at the back of the book to help you answer the next three exercises.*)

6. Make three columns on your paper. At the top of one column write the word "A Solid"; at the top of the next column write "A Liquid"; and at the top of the third write "A Gas." In each column write the characteristics that belong to that kind of material. The following list gives the characteristics: (*a*) Takes up space. (*b*) Has a definite size. (*c*) Has weight. (*d*) Takes the shape of the container that holds it. (*e*) Has no definite size. (*f*) Has no definite shape. (*g*) Has a definite shape. (*h*) Fills any vessel in which it is put.

7. (*a*) In what way is a solid different from a liquid? (*b*) In what ways is a solid different from a gas? (*c*) In what way is a liquid different from a gas?

8. Which of the following materials are solids? Liquids? Gases? Iron, glass, milk, honey, air, paper, a sponge, oil, vinegar, oxygen.

*Problems to Solve.* 1. With a vacuum-pump you can pump almost all the air from a bottle. How can you do an experiment in which a vacuum-pump is used to prove that air has weight?

2. In Figure 19 the two tumblers are standing in a pan of water. Tumbler B has water in it, while Tumbler A has only air in it. How could you fill Tumbler B with air and Tumbler A with water without taking either tumbler out of the water? Prove the correctness of your answer by actually doing the experiment.

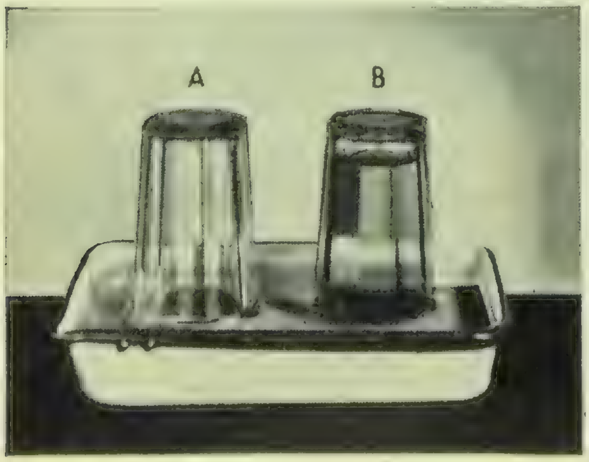

Fig. 19. Apparatus for Problem 2

3. Suppose there are two corked bottles that look exactly alike. You are told that one bottle contains air and that the air has been pumped out of the other bottle. How can you tell which of these two bottles contains air?

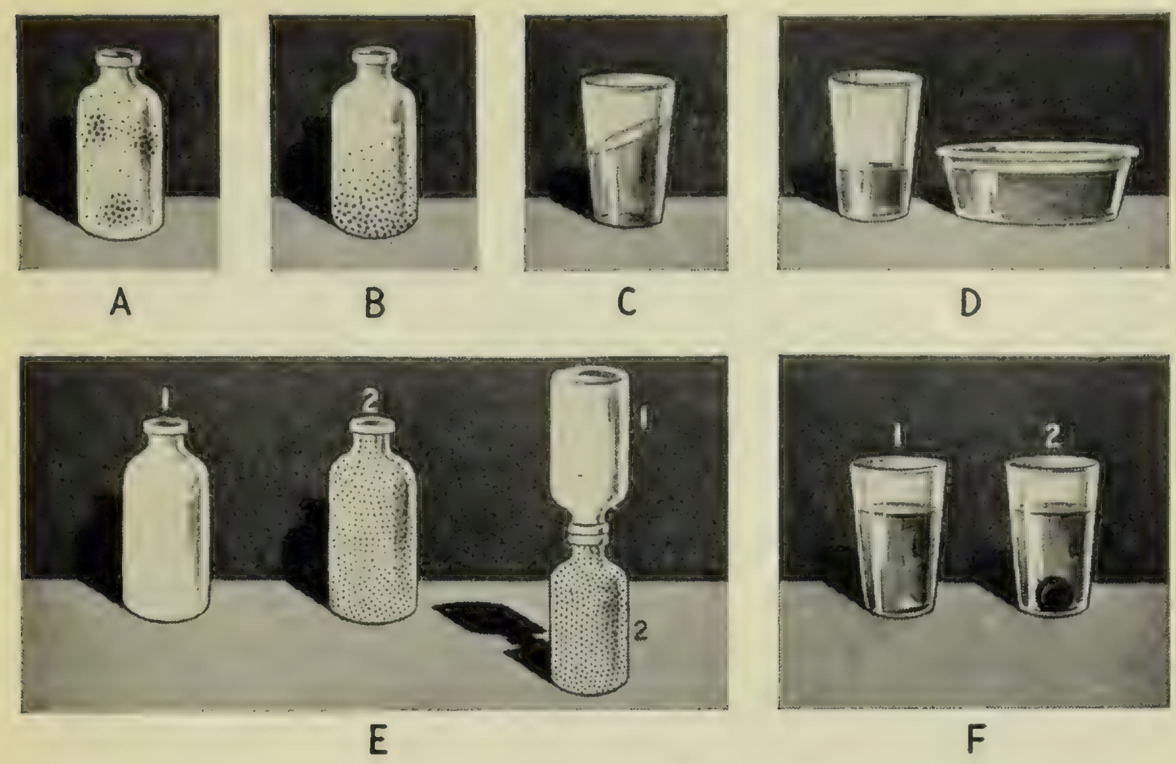


FIG. 20. Each of these drawings is wrong in some way. The problems below tell you what to do.

4. Drawing A of Figure 20 represents a bottle of air. The little dots in the bottle are particles of air. What is wrong with this drawing? Make a drawing that is correct.

5. Drawing B represents a bottle of air. The little dots are particles of air. Make a correct drawing.

6. Make a correct drawing of the glass of water in C.

7. Refer to Drawing D of Figure 20. All of the water in the pan was poured from the glass. Make a correct drawing.

8. In Drawing E Bottle 1 contains no air. Bottle 2 contains air, represented by the small dots. Bottle 1 is then placed over Bottle 2, as shown in the drawing, so that air from Bottle 2 can enter Bottle 1. Make a correct drawing.

9. In Drawing F Glass 1 contains water. Glass 2 contains an equal amount of water with an iron ball in it. Make a correct drawing.

## ¶ 2. What happens when solids and gases dissolve?

WHAT IS A SOLUTION? You have been using *solutions* all your life. Every time you put sugar in lemonade, cocoa, or chocolate, you are making a solution. If you live on a farm, perhaps you have helped spray potato plants or fruit trees to keep them from being eaten by insects and worms. If you have done so,

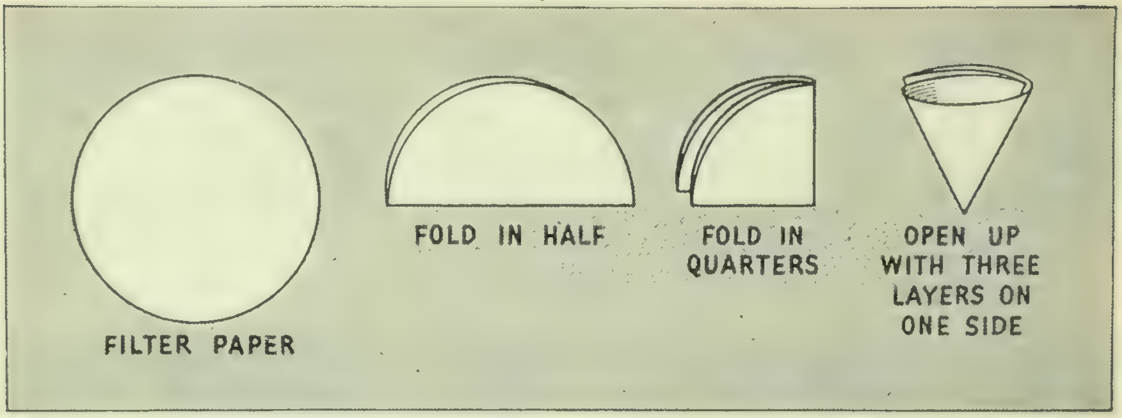


FIG. 21. Directions for folding filter paper

you were probably using a solution. Many times you have put some solid material into a liquid and have seen the solid disappear. Solutions are so important to you that you could not stay alive without them. You cannot use the food you eat or the air you breathe until they are in the form of solutions. You will learn many things about the use of solutions, but first let us learn what a solution is.

As you look down into a cup of tea, the liquid is the same color all the way through. If you take a spoonful from any place in the cup, it tastes the same as a spoonful from anywhere else in the cup. And they should taste alike, because they are the same. What you have is a solution. In this solution there are three materials: water, tea, and sugar. But you cannot tell by looking at the solution what is in it. The sugar has disappeared, and the liquid no longer looks like water.

So far you have not learned anything about a solution that you did not already know. Perhaps you had better examine some tea more carefully.

*Experiment* 3. WHAT ARE THE CHARACTERISTICS OF A SOLUTION? (*a*) Place some tea leaves in the bottom of a beaker. Add hot water. Observe what happens. Does the water change to a yellow color all at once? Or can you see the color gradually spread throughout the water?

*b*) Line a clean glass funnel or a small tin funnel with *filter paper* or clean towel paper and place the funnel in a test-tube. Be sure to fold the paper as shown in Figure 21 so that no material can get through the funnel without going through the paper. Wet the paper with clear water so that it will stay in place in the funnel. Carefully

pour some of the tea solution into the filter paper. Now examine the liquid that comes through the filter paper. (1) Is it still yellow, or did the colored material from the tea stay on top of the filter paper? Taste the filtered liquid. Is there tea in it? (2) Hold the tea solution up to the light. Is it clear or cloudy? Can you see any particles floating in it? If you have a compound microscope, put a drop of tea on a glass slide and look for yellow particles in the solution. Are they large enough to be seen with the microscope?

c) Let the test-tube of tea solution stand for several days. Does it remain the same color, or does the material from the tea settle to the bottom? Taste some of the solution by taking a little of the liquid from the top. Can you still taste the tea?

Write down three characteristics of the tea solution which you think are true of all solutions.

d) Now make two more solutions to see if they have the same three characteristics as tea solution. For one use a spoonful of sugar and for the other, a lump of copper sulphate. (Copper sulphate is used because it makes a blue color.) Do with each solution what you did with the tea in parts *a*, *b*, and *c*. (*Do not taste the copper sulphate. It is poison.*) Answer the same questions about the sugar solution and the copper sulphate solution that you did for the tea solution. In what ways are all three of these solutions alike?

We can describe what happens when a material *dissolves* by telling what happened to the sugar in Experiment 3. Tiny particles of sugar broke off from the grain of sugar and mixed with the water. This kept up until the grain of sugar was all dissolved. Since the tiny particles were too small to be seen, the sugar disappeared. The sugar particles mixed with all of the water; therefore, any teaspoonful of the solution had the same amount of sugar in it as any other teaspoonful. What is true of sugar is true of other materials when they dissolve in liquids: The solid dissolves and spreads evenly all through the liquid to make a solution.

The experiments you have done show you that solutions have three important characteristics: (1) The liquid is clear; that is, the particles of the dissolved solid cannot be seen even with a compound microscope. (2) The particles are so small that they pass through filter paper. (3) The particles stay all through the liquid; they do not settle to the bottom or rise to the top even

when the liquid is allowed to stand for several days. These three statements describe a solution. They tell us what the characteristics of a solution are.

To understand the characteristics of solutions better, let us try putting another kind of solid in water to see what happens. For this experiment use laundry starch and water. You have probably heard someone speak of dissolving starch in water to stiffen clothes. But "dissolve" is not the right word to use when we mix starch and water. You will see why it is wrong when you compare a mixture of starch and water with the solutions you made in Experiment 3.

*Experiment 4.* HOW DO WE KNOW THAT A MIXTURE OF STARCH AND WATER IS NOT A SOLUTION? (*a*) Powder the starch and stir it thoroughly into cool water. Notice whether the mixture is clear or cloudy.

*b*) Pour a small quantity of the starch mixture into a test-tube and add a drop of iodine solution. The mixture turns blue. (Cool starch always turns blue or blue-black when iodine touches it. No other substance does this. Therefore we use iodine to show whether we have starch. It is called a "test" for starch.) Now filter some of the remaining starch mixture (not the part that was tested with iodine). Add a drop of iodine solution to the liquid that passes through the filter paper. Does the starch pass through the filter paper? How do you know?

*c*) Let some of the unfiltered starch mixture stand in a test-tube for several days. Does the starch settle?

*d*) Give three reasons why you think the starch did not dissolve in the water.

CAN GASES DISSOLVE IN LIQUIDS? Just as this book was being written, the people in a certain part of Illinois began to notice a strange taste in their drinking water. The water came from wells. Scientists were asked to find out why the water had this strange taste, and this is what they discovered: For some reason a gas had formed down in the earth. This gas had slowly worked its way through the soil and into the wells, where it dissolved in the water.

Gases, as well as solids, can dissolve in liquids. You have seen some of the dissolved gas come out of a liquid. When you open a bottle of "pop," you see bubbles of carbon-dioxide gas rise to

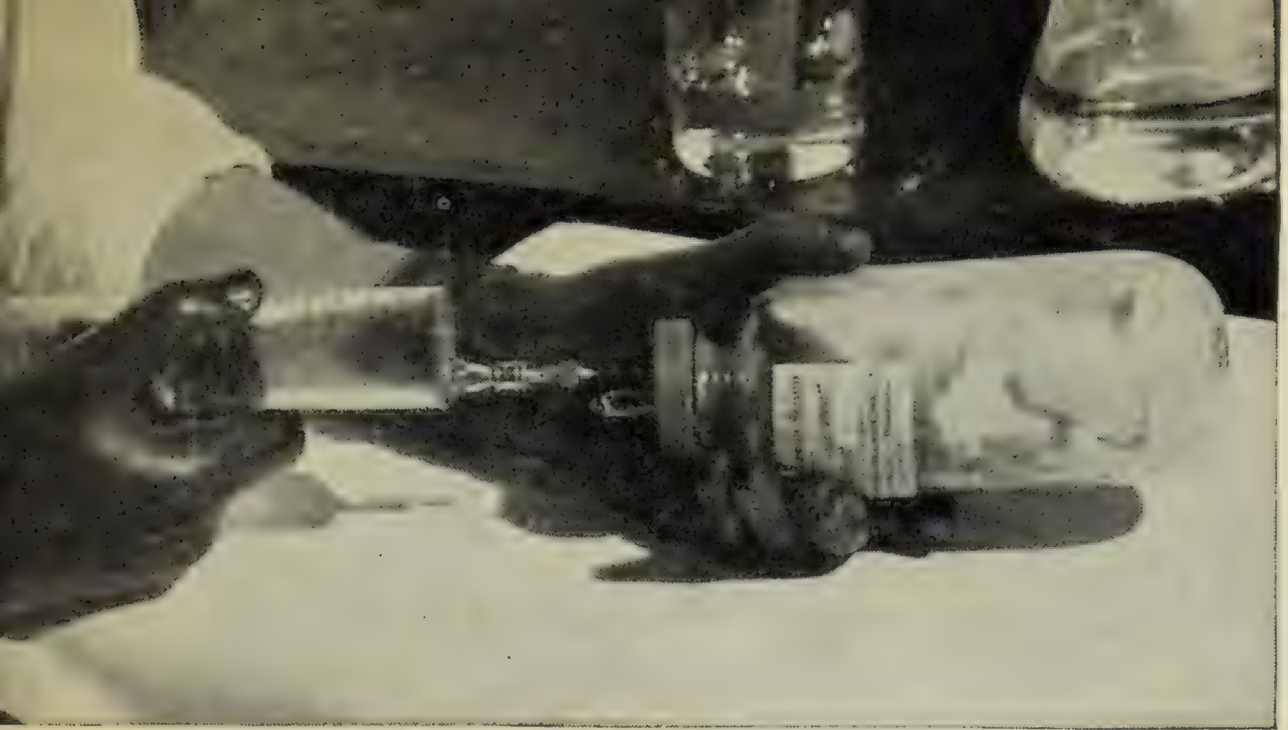

FIG. 22. Pure water put into a bottle of powdered blood serum makes a solution that doctors can inject into people who have lost blood in an accident or during an operation. The dry powder in the bottle was made from the plasma, or liquid part, of thirty-five quarts of human blood. (Black Star photo)

the top. Sometimes the bubbles come up so fast that the "pop" foams over the top. This dissolved carbon-dioxide gas gives the "pop" its sharp, stinging taste. When you heat water, little bubbles form on the bottom and sides of the pan. These are bubbles of air that have been dissolved in the water. As you go on with your science work, you will learn of many ways in which we use gases dissolved in liquids.

WHY DO WE USE DIFFERENT KINDS OF SOLUTIONS? Did you ever try to get wet paint off your hands with water? If you did, you found that it would not work. But you can try some turpentine or gasoline or kerosene. The paint will disappear like magic. Why do you suppose these liquids will remove the paint, while water will not remove it? Let us see what an experiment will show us about methods of dissolving different materials.

*Experiment 5.* HOW CAN WE DISSOLVE MATERIALS THAT DO NOT DISSOLVE IN WATER? (*a*) Get a small lump of gum camphor. Fill one test-tube half full of water and another half full of alcohol. Drop a small piece of camphor into each test-tube. Put corks in the two test-tubes, shake them, and allow them to stand overnight. What happens?

*b*) Get some butter or lard. Fill one test-tube half full of water, another half full of alcohol, and another half full of carbon tetrachloride. (Carbon tetrachloride is sold as cleaning fluid under the

name "Carbona.") Place a small piece of butter or lard in each tube. Shake the tubes and allow them to stand overnight. In which liquid does butter or lard dissolve the best?

This experiment shows why we use carbon tetrachloride instead of water to remove grease from clothing. Water will not dissolve grease. Carbon tetrachloride will. Water is the greatest dissolver in the world. It will dissolve more kinds of substances than any other liquid, but there are many substances that water will not dissolve. Therefore, scientists have spent much time in discovering what liquid or liquids will dissolve materials that they need to use in dissolved form.

For example, there could not be any rubber cement until someone was able to discover a liquid that would dissolve rubber. There was no iodine for cuts and sores until someone discovered that alcohol dissolves the hard iodine crystals. And, as you will see in Table 1, below, we would have a hard time removing stains from our clothing if we did not know how to dissolve the materials in the stains. To remove a stain, you must know first what kind of stain it is; then you can select the liquid that will dissolve the material or materials that make the stain.

TABLE 1. How to Dissolve Common Spots and Stains

| KIND OF SPOT OR STAIN | LIQUID |
|---|---|
| Blood . . . . . . . . . . . . . . | Solution of salt |
| Cocoa . . . . . . . . . . . . . . | Boiling water |
| Fruit stains . . . . . . . . . . . . | Boiling water |
| Grass stains . . . . . . . . . . . | Ether or alcohol |
| Grease . . . . . . . . . . . . . | Carbon tetrachloride |
| Paint . . . . . . . . . . . . . . | Turpentine |
| Tea or coffee . . . . . . . . . . . | Boiling water |

*Self-Testing Exercises.* 1. What are three characteristics of a solution?

2. How do you know that a mixture of starch and water is not a solution?

3. Why can you not see the particles of a dissolved solid?

4. Give two different examples of a gas dissolved in a liquid?

5. Why is the camphor solution (spirits of camphor) that the drug-store sells made with alcohol instead of with water?

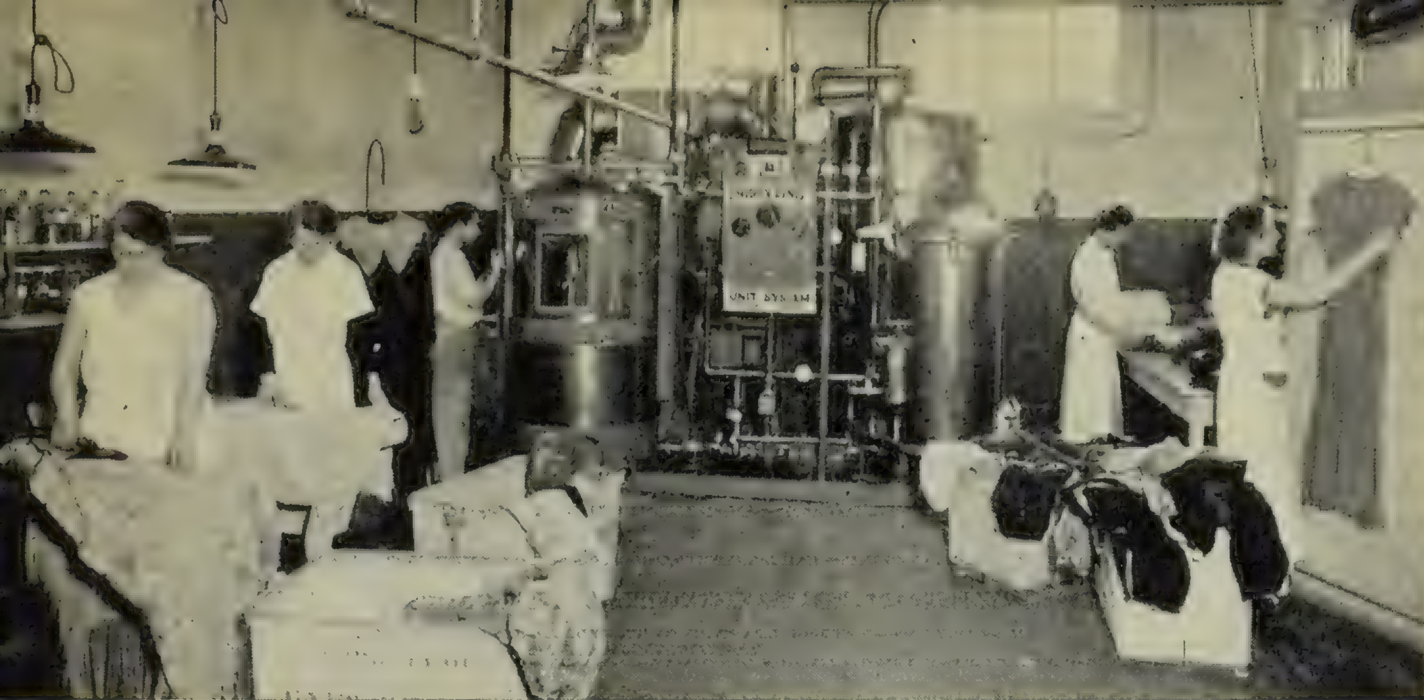

Fig. 23. In modern dry-cleaning establishments clothes are rotated in large cylinders with liquids that dissolve the grease. The bottles on the shelf at the left contain various kinds of liquids that are used to dissolve stains and remove them by hand. (Century photo)

6. Name at least two liquids (besides water) that are used in your home to dissolve materials. Think of varnishes, cleaning fluids, etc.

7. Which of the following materials do you think are dissolved in the liquid? If you do not know, how could you find out?

M a) Mud in water
S b) Salt in ocean water
S c) Sweetness and color in molasses
S d) Coloring in fountain-pen ink
S e) White material in milk
M f) White or colored material in paint

*Problems to Solve.* 1. A mechanic who has been repairing a greasy engine first washes his hands with kerosene. After that he washes with soap and water. Why does he wash with kerosene before using water?

2. When the varnished surface of furniture is scratched, you can usually rub the scratch out by using a cloth wet with alcohol. Explain.

3. The water in the ocean is salty. Explain why a layer of salt does not settle on the bottom of the ocean.

4. Make as long a list as you can of solutions that are used in your home.

5. Perfectly clear water is being used in the boilers of some locomotives. The engineers discover that the insides of the boilers are becoming covered with a coating of minerals from the water and soon will be ruined. Someone suggests that the water be filtered to remove the minerals. Will this plan work? Why?

6. In getting salt from the ground in some places, water is pumped into wells and then pumped out again. How do you suppose they get the salt from the water?

## ❡ 3. How are materials put together?

In experiment 3 the lump of copper sulphate sank to the bottom of the glass. You would expect this, since it is heavier than water. Put a lump of copper sulphate in a glass of water, as you did in Experiment 3, but allow it to stand without stirring for a week or more. A blue color appears in the bottom of the glass. Slowly the color moves upward. The lump gets smaller and smaller and finally disappears. How can the solid copper sulphate mix with the water, and how can it move upward through the water? To understand how scientists explain these things, you need to know how scientists believe materials are put together.

Fig. 24. The dots in the drawing represent a few of the molecules in a glass of air. Each arrow shows the direction in which the molecule is moving.

What is the molecular theory? Since you are only beginners in the study of science, it would hardly be fair to ask you to figure out an explanation for these facts. When scientists have an explanation that seems to be true but cannot be proved absolutely, the explanation is called a *theory*. It may still be called a theory even after everyone is sure it is correct. Let us see what theory scientists use to explain materials, or *matter*, which is the word they use to mean the same thing as materials.

First of all, scientists believe that all kinds of matter, or materials, are made of particles. These particles are called *molecules*. Therefore this theory is called the *molecular theory* of matter. Molecules are so small that they cannot be seen with the most powerful microscope. A few illustrations may help you to realize how small molecules really are. One scientist has said, "If a drop of water were magnified until it was as big as the earth, the molecules would be only as big as baseballs." In one breath a person takes about 108,000,000,000,000,000,000,000 molecules of air into his lungs. There are about as many mol-

ecules in a thimbleful of water as there are sand grains in two and one-half cubic miles of sand. It is also estimated that if the molecules in a pint jar of air were allowed to escape from the jar at the rate of 10,000,000 per second, it would take 40,000,000 years to empty the jar. These numbers are almost impossible for us to imagine. But if you get the idea that molecules are smaller than anything you ever imagined, and that the smallest bit of matter you can see with the naked eye is composed of millions of molecules, you will have a fair idea of how small they are.

Second, scientists believe that there are spaces between the molecules of matter. As you would probably expect, the spaces between the molecules of a gas are larger than those between the molecules of liquids. The spaces between molecules of liquids are usually a little larger than those between molecules of solids. It is hard to believe that materials like gold or iron really have spaces in them. However, if a piece of gold is placed in a dish of mercury (the silver-colored liquid used in thermometers), the mercury will go into the gold; that is, molecules of mercury will go in between the molecules of gold. As you will learn later, there are other reasons for believing that there are spaces between the molecules in all kinds of matter.

FIG. 25. The dots represent a few of the molecules in a dish of water. Notice that they are closer together than in Figure 24.

Another part of the molecular theory is that the molecules of all kinds of matter are always moving. It is easy to believe that the molecules of a gas or a liquid can move and do move. If gas is leaking from the kitchen stove, you can soon smell it in all parts of the house. A lump of sugar dropped in a cup of coffee soon sweetens all the liquid in the cup. It is harder to believe that the molecules of a hard metal, such as iron, gold, or silver, are moving. But they really are moving all the time. One reason for believing that the molecules of metals are moving is this: When a brass spoon is covered with silver, chemists find that a very small amount of the silver has made its way into the brass.

The best explanation we have is that the molecules of silver moved into the spaces between the molecules of the brass.

And now let us bring together the different parts of the molecular theory: (1) All matter is composed of tiny particles called molecules. (2) There are spaces between molecules. (3) The molecules are always moving. Now you are ready to explain what happened in your experiments with solutions. If the molecular theory is a good theory, it should explain the facts you observed.

HOW DOES THE MOLECULAR THEORY EXPLAIN SOLUTIONS? Now you can understand what you saw happen in Experiment 3. Molecules of the copper sulphate separated from the lump and went into the spaces between the molecules of water. But even then they did not stop. They kept bouncing around among the molecules of water until some of them finally got to the top of the water. More and more molecules separated from the lump and went into the spaces between the molecules of water until finally the lump was gone. When the glass was held to the light, no solid particles could be seen in the water, because molecules are so tiny.

FIG. 26. This picture shows copper sulphate molecules going into the spaces between the molecules of water (shown as white circles).

This is what takes place in all solutions. The molecules of the solid pass in between the molecules of the liquid and travel to every part of the liquid. They are moving rapidly, and they are kept apart from each other by the water; therefore they do not settle to the bottom even though they are heavier than the water.

The molecular theory also explains why a solution can be filtered while a mixture of starch and water cannot be filtered. In a solution the particles are in the form of molecules. The molecules are so tiny that they can pass right through small holes in the filter paper. In the mixture of starch and water the particles of starch are hundreds or thousands of times larger. They cannot pass through the filter paper.

You have seen that the molecular theory does explain the facts you observed in your experiments. If we are good scientists, we will not accept the theory until we have tried it out to see whether it fits many other facts. Let us see how the theory works in explaining other things you know. If an unlighted gas jet is opened, in a very short time you smell the gas in all parts of the room because gases usually spread out to fill whatever space they are put in. Have you ever come home from school and said as you opened the door, "We are going to have onion soup for supper"? In both cases molecules must have entered your nose—in one case molecules of gas and in the other case molecules of onion. To get to your nose they must have moved through the air. The molecular theory explains these facts satisfactorily.

You have probably noticed that after an automobile tire has been pumped up, it is still possible to force in more air. How can this be explained? The pump pushes more molecules of air into the tire. When this happens, the molecules of air in the tire must be crowded closer and closer together. This is clearly explained by our theory, which says that there are spaces between molecules. Scientists use the molecular theory in many ways to explain how matter acts. You also will use the theory many times in your science work.

*Self-Testing Exercises.* 1. What word do scientists use to stand for all materials?

2. Why do scientists think up theories?
3. How is a theory different from a fact?
4. What is the molecular theory?
5. Explain the following by using the molecular theory:

*a*) A small amount of coloring matter may color a whole glass of water.
*b*) Mercury can go into gold.
*c*) Silver can be found in the metal upon which it is plated.
*d*) The odor of perfume spreads throughout a room.
*e*) An air-pump can force air into a tire that already has much air in it.

6. Why do you think that the molecular theory is probably true?

(*Explain the following problems by what you have learned about the molecular theory.*)

*Problems to Solve.* 1. If a little sugar is added to water, it disappears. If you hold the mixture to the light, you cannot see the

particles of sugar. Why not? If the mixture is run through a piece of porous paper, like towel paper, no sugar is found on the paper. Explain.

2. Air, as you probably know, is a mixture of various kinds of gases: oxygen, nitrogen, water vapor, carbon dioxide, and others. Carbon dioxide is much heavier than the other gases. Why is the carbon dioxide mixed all through the air instead of being collected near the ground?

3. You know that a wet cloth soon dries. Is this fact explained by the molecular theory? How?

4. If moth balls are placed in the pocket of a coat hung in a clothespress, the smell of the moth balls soon spreads to all parts of the clothespress. Explain.

5. Your mother does not put cooked cabbage in the ice-box because it will give butter the taste of cabbage. Explain how the butter takes on the flavor of cabbage.

6. A boy brought home a rubber balloon filled with hydrogen gas. When he went to bed, the balloon was tightly filled and floating against the ceiling of the room. When he awoke next morning, the balloon had lost most of its hydrogen and was lying on the floor. The boy could find no hole in the balloon. How could the hydrogen have escaped?

7. If the hole in the bottom of an ordinary red flower-pot is sealed with wax and the pot is filled with water, the outside of the pot soon becomes moist. Explain how the water can get through the pot.

## ¶ 4. What kinds of materials do we have?

WHAT ARE ELEMENTS AND COMPOUNDS? How many kinds of materials do you suppose there are? So far, chemists have named over 300,000 different kinds. Some of them are solids; some are liquids, and some gases. If you could say them at the rate of eighty a minute, it would take you over sixty hours to name them all. Of course, you will not have time in this science course to study all of these materials. You will study only a few of them, but from your study you will find out many things that are true of all materials.

You will start your study by doing an experiment. In this experiment you will make something happen that seems to be impossible. All that you have to do is to heat a certain kind of

red powder in a test-tube. This does not sound very exciting, but you will never guess what will happen. Do not expect a rabbit to jump out of the test-tube. Even a scientist cannot change a red powder into a rabbit. But he can change this powder into something else, and you can do so, too.

*Experiment 6.* WHAT HAPPENS WHEN MERCURIC OXIDE IS HEATED? First, pour a little of the mercuric-oxide powder (about enough to make a layer one-quarter inch deep) into the test-tube. Use a Pyrex or hard glass test-tube, if possible. In the mouth of the tube, put a paper plug. Then fasten the test-tube in a clamp just over the hottest part of a Bunsen-burner flame (Figure 27). After a minute or two, look at the sides of the tube about halfway to the top. What do you see? If you look closely, you will see a silvery material.

Now light a wood splinter. Let it burn a little, and then blow out the flame so that the splinter is just glowing. Remove the plug and plunge the glowing splinter into the test-tube. What happens? Notice how brightly the splinter burns.

Now heat the test-tube until all of the red powder is gone. Then scrape some of the silvery material out of the tube. What is it? It is mercury.

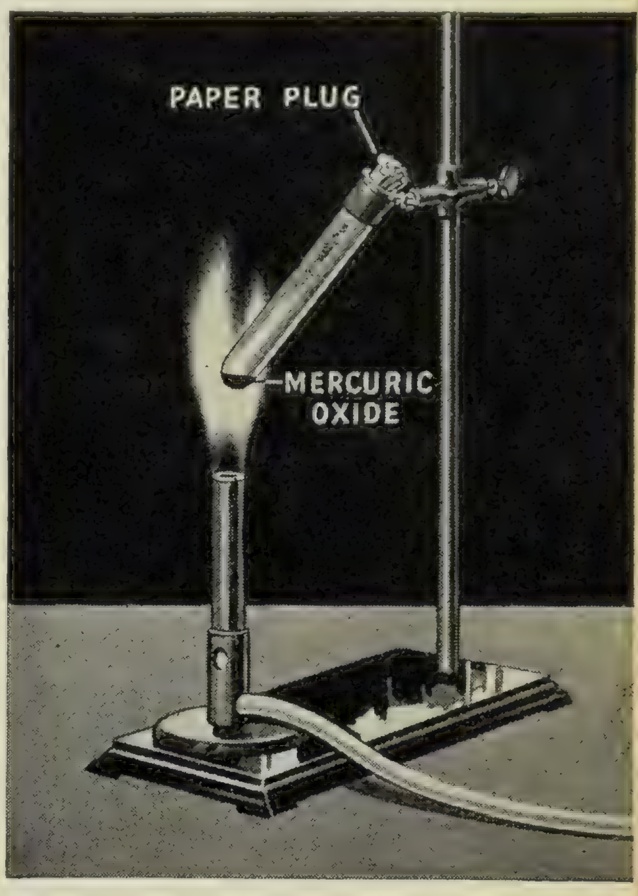

FIG. 27. Apparatus for Experiment 6

Wouldn't you call this a good magical experiment? Who would ever think that from a red powder you could get a silvery liquid and a gas that makes things burn more brightly? Now that you have seen this happen, you of course want an explanation. How can a red powder change into mercury and a gas? One thing we can be sure of: The mercury and the gas must have come from the red powder. There was no other material for them to come from. This, of course, can mean only one thing: The red powder must be made of two materials, mercury and some kind of gas. From its name, *mercuric oxide*, you might have guessed that the red powder was made of mercury and oxygen. When

you heated the red powder, you must have caused it to separate into the materials of which it is made.

A material, such as mercuric oxide, that contains two or more simpler materials, is called a *compound.* The simpler materials that make up the compound are called *elements.* Elements cannot be separated into simpler materials. They are made of only one kind of material. Iron, gold, silver, mercury, and oxygen are examples of elements. No matter what we do with them, we cannot separate them into simpler materials.

A strange thing about a compound is that we cannot see any of the elements in it. You can grind mercuric oxide into the finest kind of powder and look at it under the most powerful microscope, and still you will not see any silvery liquid. Perhaps another example will make this clearer. Water is a compound. It is made of two gases, hydrogen and oxygen. Hydrogen is the gas that was used to fill the dirigible *Hindenburg.* You will remember that the hydrogen caught fire, and the dirigible was destroyed. Oxygen, as you know from Experiment 6, is the gas in which things burn brightly. Here we have an example of a gas that will burn and of a gas that makes things burn; we put them together, and they form a liquid that we use to put out fires. Strange, isn't it?

So we cannot tell whether a material is an element or a compound by looking at it. Even if we know that a material is a compound, we cannot tell by looking at it what elements are in it. But there is one kind of man who makes a business of doing this. That man is the chemist. As you study more about science, you will learn of many other wonderful things that the chemist can do with materials.

WHAT ARE SOME COMMON ELEMENTS AND COMPOUNDS? Through years of experimentation and discovery chemists have found only ninety-six different elements. Some elements are hard, shiny substances, such as iron, copper, nickel, aluminum, silver, gold, and zinc. The element mercury is a liquid. Other elements, such as hydrogen, oxygen, helium, nitrogen, and chlorine, are gases. The 300,000 different materials in the world are made from less than 100 elements. Think of that! If you could take apart everything in the world,


FIG. 28. How many of the common elements in this collection do you recognize? The wire, or filaments, in the electric-light bulb are tungsten. The faucet handle is iron, plated with chromium. Most toothpaste and shaving-cream tubes are made of tin.

from roller-skates and candy to elephants and trees, and put the materials in separate piles, you would have less than 100 different piles. We might call these different elements the building blocks of our materials. Sometimes we make things from the elements themselves, as with gold and lead. Sometimes we put elements together because we need the compounds that can be made with them.

Even our bodies are made of elements. A scientist has figured out that the body of a man weighing 160 pounds contains enough iron to make a tenpenny nail, a small teaspoonful of sugar (a compound made of carbon, hydrogen, and oxygen), enough fat (a compound of carbon, hydrogen, and oxygen) to make several bars of soap, several cups of lime (calcium), enough phosphorus to make a large box of matches, and enough potassium to make the powder for a small shot-gun shell.

It would be very interesting to make a collection of the different elements. You will find, however, that many of them are hard to obtain. Table 2, on the next page, gives a list of the most common elements and some of their characteristics and uses. Following each element you will find in the next column the *symbol*, or sign, for the element. Instead of writing the whole word, the chemist uses one or two letters to stand for the name of the element. If you study chemistry, you will learn the symbol for each of the different elements, but it is not necessary for you to do so now. You may wish to memorize a few of them just for fun.

TABLE 2. SOME COMMON ELEMENTS

| ELEMENT | SYMBOL | CHARACTERISTICS | USES (EITHER ALONE OR IN COMPOUNDS) |
|---|---|---|---|
| Aluminum | Al | Light, silver-colored metal | Kitchen pans, aeroplane parts |
| Calcium | Ca | Silver-white metal | Compounds: limestone, quick-lime, mortar, bleaching powder |
| Carbon | C | Black solid or clear crystals | Pencils, coal, diamonds |
| Chlorine | Cl | Greenish-yellow poisonous gas | Bleaching compounds, table salt; used to kill germs |
| Chromium | Cr | Silver-white metal | In stainless steel and rust-proof plating |
| Copper | Cu | Brownish-gold metal | Kitchen utensils, wire for electric current |
| Gold | Au | Yellowish metal | Jewelry, fillings for teeth |
| Helium | He | Light colorless gas | Inflating balloons |
| Hydrogen | H | Light colorless gas | Inflating balloons, blow-torches |
| Iodine | I | Purplish-black crystal | Killing germs |
| Iron | Fe | Silver-white metal | Construction purposes |
| Lead | Pb | Soft bluish-white metal | Paint, pipes, solder, shot |
| Magnesium | Mg | Soft, silvery metal | Asbestos, medicine, talcum powder |
| Mercury | Hg | Silver-colored liquid | Thermometers, barometers |
| Neon | Ne | Colorless gas | Advertising signs |
| Nickel | Ni | Hard silver-white metal | Coins, plating other metals |
| Nitrogen | N | Colorless gas | Fertilizers, explosives |
| Oxygen | O | Colorless gas | Burning, blow-torches |
| Phosphorus | P | Waxy yellow solid | Matches, rat poison |
| Platinum | Pt | Soft white metal | Jewelry, wire |
| Potassium | K | Waxy bluish-white metal | Soap, baking-powder |
| Silicon | Si | Brown solid | Sand, glass |
| Silver | Ag | Soft white metal | Coins, jewelry, mirrors |
| Sodium | Na | Waxy silver-white metal | Table salt, baking-soda, etc. |
| Sulphur | S | Yellow solid | Matches, fireworks, gun-powder, dyes |
| Tin | Sn | Soft white metal | Tin-foil, plating, solder |
| Tungsten | W | Heavy silver-white metal | Electric lamp filaments |
| Zinc | Zn | Bluish-white metal | Electric batteries, covering on galvanized iron |

Table 3 gives a list of some of the common compounds. How many of them do you know? You will also find the *formula*, or abbreviation, for each of the compounds. In some of these formulas there are little numbers. You do not need to know exactly what these numbers mean, but the chemist uses them to tell how much of each element it takes to make the compound.

Notice that each formula contains two or more symbols. You would expect this, because compounds are made of two or more elements. From this table you can tell what elements are in each compound. For example, let us take table salt. The chemical name is *sodium chloride*, and the formula is NaCl. Na stands for sodium, and Cl stands for chlorine. In Experiment 6 you discovered that mercuric oxide contains mercury and oxygen. The chemical formula for mercuric oxide is HgO. Hg stands for mercury, and O stands for oxygen. From Table 2 see if you can tell what elements are in each compound in Table 3.

TABLE 3. SOME COMMON COMPOUNDS

| COMMON NAME | CHEMICAL NAME | FORMULA | USES |
|---|---|---|---|
| Alcohol | Ethyl alcohol | $C_2H_5OH$ | Dissolving things |
| Alum | Potassium aluminum sulphate | $KAl(SO_4)_2$ | Baking-powder |
| Ammonia water | Ammonium hydroxide | $NH_4OH$ | Cleaning |
| Baking-soda | Sodium bicarbonate | $NaHCO_3$ | Baking |
| Blue vitriol | Copper sulphate | $CuSO_4$ | Killing fungi and copper plating |
| Carbona | Carbon tetrachloride | $CCl_4$ | Cleaning fluid |
| Chile saltpetre | Sodium nitrate | $NaNO_3$ | Fertilizer |
| Chloroform | Trichloromethane | $CHCl_3$ | Anaesthetic |
| Limestone | Calcium carbonate | $CaCO_3$ | Building |
| Lye | Sodium hydroxide | $NaOH$ | Cleaning, soap making |
| Plaster of Paris | Calcium sulphate | $(CaSO_4)_2 \cdot H_2O$ | Molds and casts |
| Quicklime | Calcium oxide | $CaO$ | Mortar |
| Sand | Silicon dioxide | $SiO_2$ | Building |
| Sugar (cane) | | $C_{12}H_{22}O_{11}$ | Food |
| Table salt | Sodium chloride | $NaCl$ | Seasoning food |
| Washing-soda | Sodium carbonate | $Na_2CO_3$ | Washing, glass making |

*Self-Testing Exercises.* 1. What is a compound?

2. How is an element different from a compound?

3. Can you tell what elements are in a compound by looking at it? Give an example to help explain your answer.

4. We say that elements are the building blocks of other materials. What do we mean by this?

*Problems to Solve.* 1. List the elements in Table 2 that you have heard of. Place a star in front of those in your list that you have seen.

2. Refer to Table 3 and find all the compounds that contain sodium. How do these compounds help you understand why so many materials can be made from less than 100 elements?

3. When someone tells you that gold is an element, what do you immediately know about gold?

4. Iron rust is a compound. What does this tell you about rust?

## ¶ 5. Why do materials have weight?

WHAT IS "WEIGHT"? For several years you have been very much interested in the pull of gravity. Every time you have stepped on a scales to weigh yourself, you have wanted to know how hard gravity was pulling on your body. As you grew, your body was adding more matter to itself. You found that each year gravity was pulling harder on you because there was more of you.

Have you ever wondered just what gravity is? What queer kind of "rubber band" must be attached to everything to pull it back to earth after it has been lifted up? About 275 years ago a falling apple set Sir Isaac Newton wondering about gravity. What makes an apple fall down instead of up? How far out into space does gravity go? Can it reach as far as the moon? If it does, why doesn't the moon fall on the earth? Does gravity pull on everything? And, if so, does it pull on all things with equal force? Newton did not stop thinking about gravity at the end of five minutes or of five days. He continued his study of gravity for a long time and worked out many hard mathematical problems that helped him find answers to the questions he had been wondering about.

For a long time scientists have been trying to find out what gravity is, but they cannot yet explain to us what it is. There-

fore, when we study gravity, we can only study what it does. Pick up the nearest book. Hold it out and let go of it. You know what will happen without doing the experiment. You say that any object that is not held in some way will fall down to the ground. But which way is "down"? It is always toward the earth. If you drop an object at any place on the earth's surface, it will always go down, that is, toward the earth. Figure 29 shows what happens when objects are dropped at different places around the earth. It is just as if the force of gravity were concentrated at the centre of the earth. Of course, if the wind or something else gives a falling object a push to one side, it does not fall straight down. But the pull of gravity is, in most places, toward the centre of the earth.

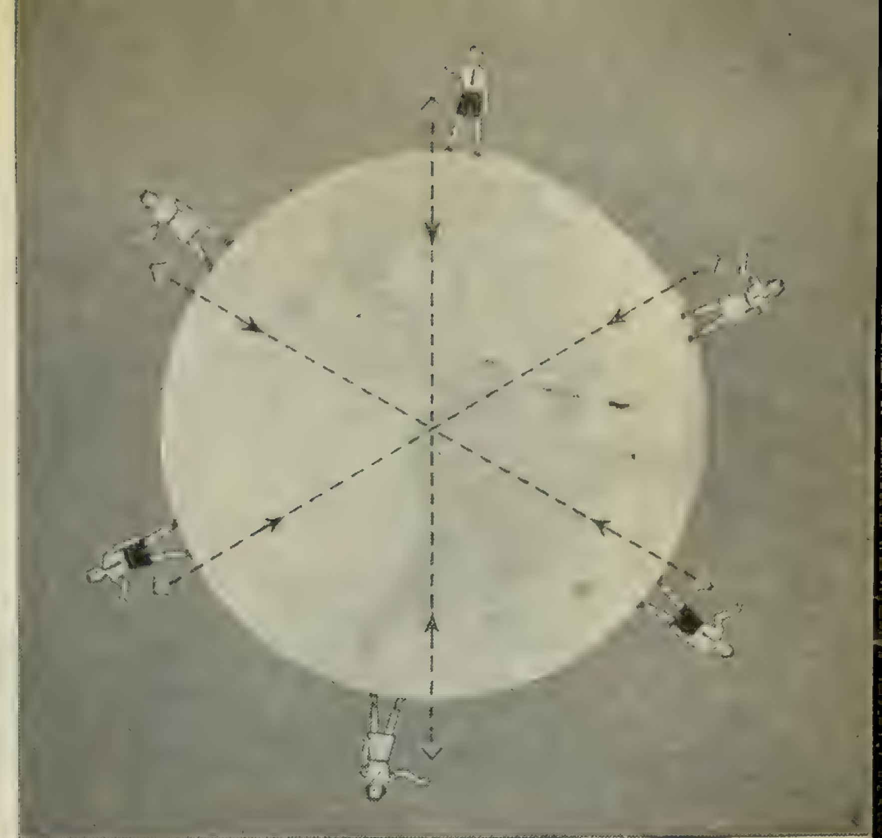

FIG. 29. If you imagine that objects keep on falling into the earth, you find that they meet at the centre of the earth.

But why do we use scales to weigh things, and what do we mean when we say that something weighs so many pounds or *kilograms?* When men first began to measure amounts of materials, they used a number of different ways. One of the most common ways was to use a stone of convenient size. If they wanted some wheat, they would pour wheat into a basket until the wheat weighed as much as the stone. In other words, they compared the pull of gravity on the wheat with the pull of gravity on the stone. When the pull was the same, they said that they had a "stone" of wheat. In England today it is still common to hear people say that a person or an animal weighs so many "stone." A "stone" now means fourteen pounds.

What you do in weighing, then, is to compare the pull of gravity on the piece of matter you want to know about with its pull on weights that have a known amount of matter. This comparison is made in different ways. Scientists use balances with equal arms on the two sides of a pivot, as shown in Figure 15.

FIG. 30. These are standard kilograms such as are kept at the Bureaus of Standards in various countries. They are 90 per cent platinum and 10 per cent iridium. These metals will not rust. (National Bureau of Standards photo)

The object or material to be weighed is placed on one side and known weights are added to the other side until the two sides balance. Then the scientist knows that the amount of matter in the object is the same as that of the weights he placed on the other side, because the pull of gravity on the two sides is the same. Sometimes grocery stores use scales that work the same way. If you buy a pound of meat, the butcher places a pound weight on one side of the balance and adds meat to the other side until the two sides balance.

Springs can be used for weighing because, if they are not loaded too heavily, they stretch twice as far for two pounds of pull as for one, three times as far for three pounds, and so on. However, springs can be overstretched. They also may expand and contract with changes in temperature. These changes will make them inaccurate; therefore, they are not used where great accuracy is needed. But they are widely used in commercial work, because the amount of error is usually small.

WHAT ARE TWO SYSTEMS OF WEIGHING MATTER? When people first began to weigh things, they used many different standards, like the stone you read about on page 55. But at last they came to see that they must have standards that meant the same to everyone. The standard unit of matter is a piece of metal kept in the International Bureau of Weights and Measures at

Sèvres, France. It is a solid cylinder made of platinum and iridium. A very accurate copy of it is kept at the Bureau of Standards in Ottawa. All the important nations of the world have agreed that this weight shall be the standard for measuring the amount of matter in things. This standard of weight is called one kilogram.

The system of weight that is based on the kilogram is called the *metric system*. This is used by scientists everywhere and for trade in most countries except the British Empire and the United States. The system based on the pound is called the *English system* and is commonly used in English-speaking countries. Some common units of the metric system of weights and their equivalents in the English system are shown in Table 4.

TABLE 4. Metric Units of Weight and Their Practical English Equivalents

| | | | | |
|---|---|---|---|---|
| 1000 milligrams | = | 1 gram (g.) | = | 1/28 ounce |
| 1000 grams | = | 1 kilogram (kg.) | = | 2.2 pounds |
| 1000 kilograms | = | 1 metric ton | = | 2204.6 pounds |

WHAT IS THE DENSITY OF A MATERIAL? Has anyone ever asked you this question, "Which is heavier, two pounds of feathers or a pound of lead?" This question confuses many people for a moment because we have two meanings for the word "heavy." You are correct when you say that two pounds of feathers are heavier than a pound of lead. You are also correct when you say that lead is heavier than feathers. To avoid confusion of this kind in thinking about the pull of gravity on materials, scientists use a word that is helpful to all of us. That word is *density*.

The density of any substance is the amount of matter of that substance in a certain space. For example, the density of cork is 15.6 pounds per cubic foot, that of water is 62.4 pounds per cubic foot, and that of lead is 705 pounds per cubic foot. Notice that in thinking about density you have to think about space, too. Density tells you how much matter will go into a certain amount of space. A box with one cubic foot of space in it will hold over 700 pounds of lead, but only about fifteen pounds of


FIG. 31. You can easily carry a cubic foot of cork under your arm, and you can just about lift a cubic foot of ice. But you cannot budge a cubic foot of iron.

cork. Lead is a much denser material than cork. Different kinds of liquids also have different densities. A cubic foot of space holds 62.4 pounds of water, about 42 pounds of gasoline, and 849 pounds of mercury.

Now if you have really understood the explanation, your answer to the "catch" question will be, "Lead is denser than feathers, if that is what you mean." And you will not be fooled if someone says: "Which is heavier, a pound of cheese with holes in it or a pound of cheese without holes in it?"

*Self-Testing Exercises.* 1. Explain how gravity is used to measure matter.

2. Explain why spring scales are seldom used for very accurate weighing.

3. (*a*) What is the metric system of weights? (*b*) Who uses it? (c) Give one advantage it has over the English system.

4. What is the standard unit of matter for the world?

5. What does the word *density* mean? Give the density of water and of one other substance as examples.

*Problems to Solve.* 1. How many kilograms do you weigh?

2. About how many grams are there in a pound of sugar?

3. Examine several different scales or balances used for weighing things. Try to see how each kind works. If at all possible, make diagrams of the working parts to show how they compare the pull of gravity on a known weight with that on an unknown amount of matter.

4. Find in a reference book a table of densities and get the densities of some common materials. Make a list, beginning with the material of greatest density.

density = weight per unit volume.



5. Find the density of water in the metric system. Can you think of any advantage of having the density such a convenient number?

6. Plan a way to find the density of a block of wood or stone. If possible, try your plan.

## Looking Back at Unit 2

1. Here is a suggestion that will help you look back at Unit 2 to see what new ideas you got from it: Give a good answer to each big problem of the unit. Use several sentences for an answer if you really need them. The questions below will help you.

*a*) How are all materials alike?

*b*) What is a solid? A liquid? A gas?

c) What are the characteristics of a solution? How do we use solutions?

d) What are molecules? How do they behave in solids? In liquids? In gases? How do they behave when a material dissolves?

e) What are elements and compounds?

*f*) What does "weight" mean?

2. Explain or define each of the following important science words used in this unit.

| | | | |
|---|---|---|---|
| *material* | *density* | *weight* | *metric system* |
| *solid* | *molecule* | *matter* | *theory* |
| *gas* | *element* | *mixture* | *kilogram* |
| *chemical symbol* | *liquid* | *compound* | |
| *chemical formula* | *solution* | *gravity* | |

## Additional Exercises

1. Fred was filling a bottle with water. The funnel he was using fitted tightly in the neck of the bottle. Even though he had the funnel full of water, it ran into the bottle very slowly. Which characteristic of matter did Fred forget? How could he have filled the bottle more quickly?

2. In this unit you learn that all matter has two characteristics: It fills space, and it has weight. Every material has at least two other characteristics. Find out what they are.

3. Make some lemon "soda water." Obtain a clean bottle with a screw top or some other kind of top that can be held on against considerable pressure from the inside. Put one teaspoonful of baking soda in the bottle and fill it half full of cool water. Now pour in four teaspoonfuls of lemon juice and fasten the top on quickly.

Watch what happens. When the action in the bottle has stopped, pour some of the water out into a glass and see what happens. What kind of solution did you make?

4. Suppose that you were given a test-tube containing a liquid and were asked if the liquid had materials in solution. Work out an experiment to help answer the question.

5. What is the difference between the meaning of the word *liquid* and the meaning of the word *fluid?*

6. According to Problem 1, two materials cannot be in the same place at the same time. When you make a solution of sugar in water, are not the sugar and water in the same place? Explain your answer.

7. Make a "crystal basket." First, make a small basket of cotton-covered copper wire and a small string of thread. Make it small enough to go inside a large beaker. Make enough hot solution of copper sulphate to cover the basket. Keep adding copper sulphate to the solution until it is very strong. Lower the basket into the solution and allow it to cool slowly. Will hot water or cold water usually dissolve the most material?

## Books to Read

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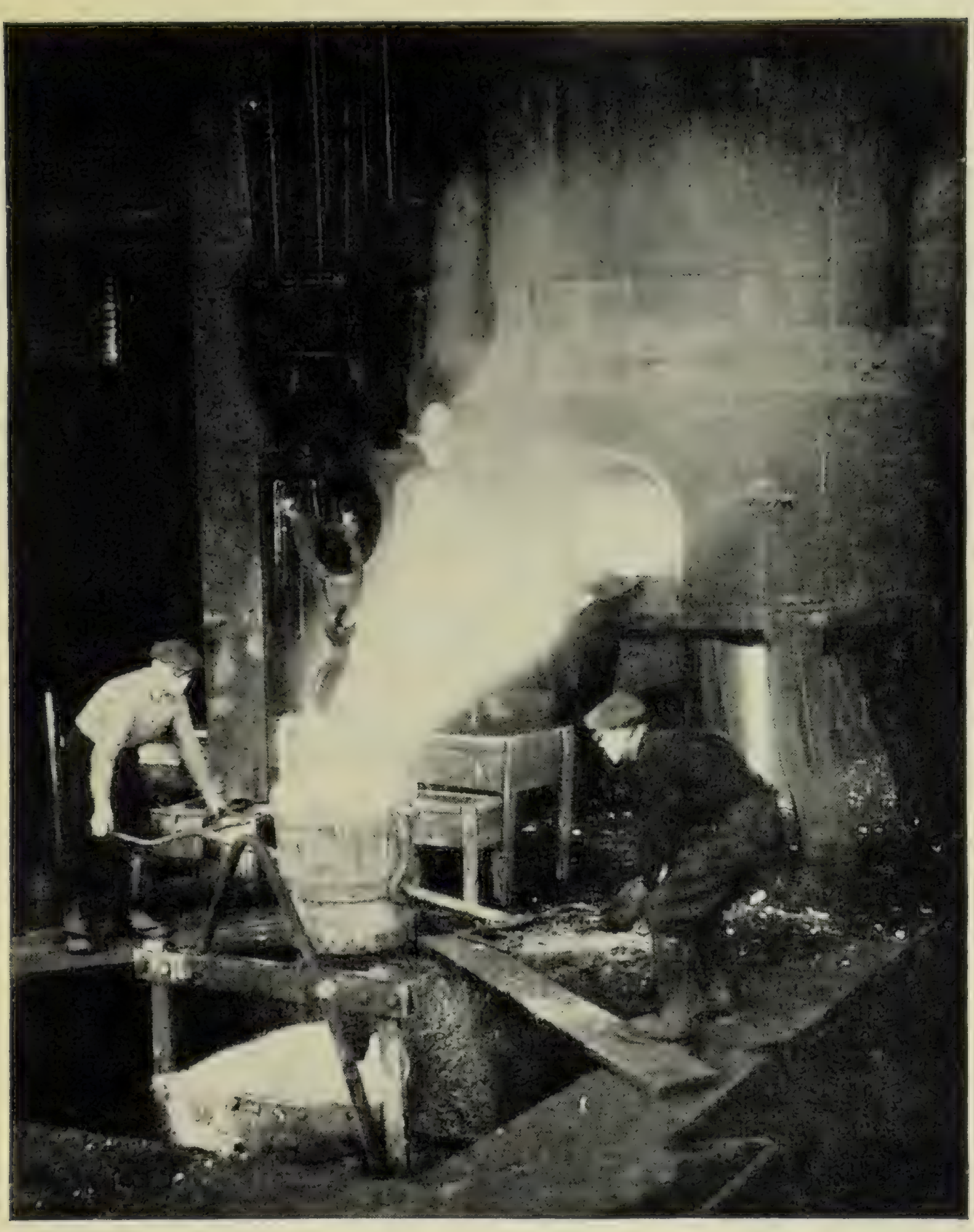

Ever since the world began the materials in and on the earth have been changing. When men learned how to be scientists, they, too, began to make materials change, so that they could have new and different materials to use. They changed many materials by heating or cooling them. By heating iron ore to a temperature of more than 3000 degrees, they were able to melt it. In this unit you will find out many things about how materials change. (Climax-Molybdenum Co. photo)

# UNIT 3

# How Can Materials Be Changed?

## Looking Ahead to Unit 3

SUPPOSE SOMEONE ASKED YOU whether you could change a quart of water into more than a quart of water. What would you say? You know that a certain amount of water will take up just so much room, or space. Would it be possible to make a quart of water take up more space? According to what you know, this seems impossible. Maybe it is impossible, but, if so, how do you explain this experience which almost everyone has had? You fill a kettle with water, place it on the stove, turn on the heat, and go into the other room to read. After awhile you hear a sputtering, hissing noise in the kitchen. Much to your surprise, you find that the water is running out from the top of the kettle. There must be more water in the kettle than there was when you put it on the stove. Does this seem to show that you can make a quart of water equal more than a quart of water?

If you can get a rubber balloon, try this experiment. Fill the balloon with air and then hold it over a hot stove. You will see that the balloon gets larger. If you get it hot enough, it may burst. Now how do you explain this? Of course you know that air occupies space. You know that if you put more air into the balloon, it will get larger. But you have not put any more air into the balloon. And still it gets larger. Curiously enough, the air in the balloon seems to act in the same way as the water in the kettle. What do you suppose heating does to materials like water and air?

One day at home a boy tried to open a bottle that had a glass stopper. He used all his strength, but he could not budge the stopper. Finally he asked his mother what to do, and she said, "Pour some hot water on the neck of the bottle." He

FIG. 32. Probably you have seen a concrete pavement or a sidewalk that has bent and cracked like this one. Did you know that heat caused this surprising thing to happen? (Indiana State Highway Dept. photo)

tried this, and the stopper came out quite easily. Here again you see that heating a material changed it in some way. How do you explain what happened to the neck of the bottle when hot water was poured on it?

But there are still more strange things that can and do happen to materials. In Unit 2 you made a red powder change into a silvery liquid and an invisible gas when you heated it. You have probably seen the shiny, hard steel of a knife blade change to a brown, crumbly material that we call rust. You know that the hard, yellowish-white wood of a tree that has just been cut down slowly crumbles into a soft brown material that is of no use to us. We say that it decays. Do you know what happens to the film of a camera when you take a picture? Do you know what happens to the film when you develop it? Why do iron and steel rust, wood decay, and cloth fade? As you will learn later, plants make themselves out of materials they get from the soil and air. You eat plants for food, but you cannot stay alive by eating soil and breathing air. Why not? How can plants make food out of materials that you and I cannot use for food?

To answer all these questions you need to know many things about how materials change—from solids to liquids to gases and from gases to liquids to solids. You will also need to know how elements and compounds can be juggled around into all sorts of different combinations to make thousands of materials that we need. In Unit 1 you read about some of the amazing things that scientists can do with materials. In this unit you will learn why and how they can do these things.

FIG. 33. Apparatus for Experiment 7

## 1. How do heating and cooling change materials?

HOW DO HEATING AND COOLING CHANGE THE SIZE OF SOLIDS? You have just read about some everyday happenings that need to be explained. You have learned that solids, liquids, and gases take up a certain amount of space. When materials are heated, it seems that they take up more space than they did before they were heated. But before you decide to believe this, you will want to test it to see if it is true. You can begin testing the idea by heating a copper wire.

*Experiment 7.* WHAT EFFECT DO HEATING AND COOLING HAVE UPON A COPPER WIRE? Attach a piece of copper or iron wire about two feet long to two iron stands or other supports (Figure 33). Hang a small weight from the centre and stretch the wire as tightly as possible. Carefully mark the distance of the weight above the table. Now heat the wire along its whole length with a Bunsen burner or other flame. Again notice the height of the weight. Does the height change? How does the length of the hot wire compare with the length of the cold wire? Now allow the wire to cool. What happens? What is your answer to the problem you were trying to solve?

We may tell what happened in the experiment in the following words: The wire *expanded*, or got longer, when it was heated. It *contracted*, or got shorter, when it was cooled If you had a way to measure the wire, you would also find that it

got thicker, or wider, too. The wire thus got bigger; that is, it expanded in all directions when it was heated. Is this true for other solids as well? This question can only be answered by further experiments with other solids. Fortunately, scientists have already done these experiments, and they have found that most solids expand when heated and contract when cooled.

Before you leave this problem, you should think more about what you have learned. That most solids expand when heated and contract when cooled is a *principle of science*. A principle of science is a statement that tells what happens under certain conditions. Scientists discover what happens by experimenting. By experimenting you discovered what happens when a metal is heated or cooled. Of course, scientists experimented with many different kinds of solids to see whether all of them changed in size when heated or cooled. Then they made a statement to tell what they had discovered about the effect of heat on solids. This statement (that solids expand when heated and contract when cooled) is a principle of science.

Sometimes we find exceptions to the principle; that is, the principle is not true in some one case. However, there are very few exceptions to a science principle, and we are usually safe in using the principle to explain the things we see happening. When you have learned a principle of science, you find that it may be used to explain a great many things. That is why a very important part of your science study is learning principles of science. To show you how valuable science principles are, let us examine a few things that you see happening almost every day.

If you help your mother wash the dishes, you know that you should never pour very hot water on thick glass tumblers or other thick glass dishes. If you do, the glass will often crack. You can explain what happens by using the principle you have just learned. The hot water causes the glass to expand. If the glass is very thick, it will not get heated all the way through at once. The outer surface of the glass will become heated before the inside. The outside of the glass will thus expand faster than the inside of the glass. Something has to give way; so the glass cracks.

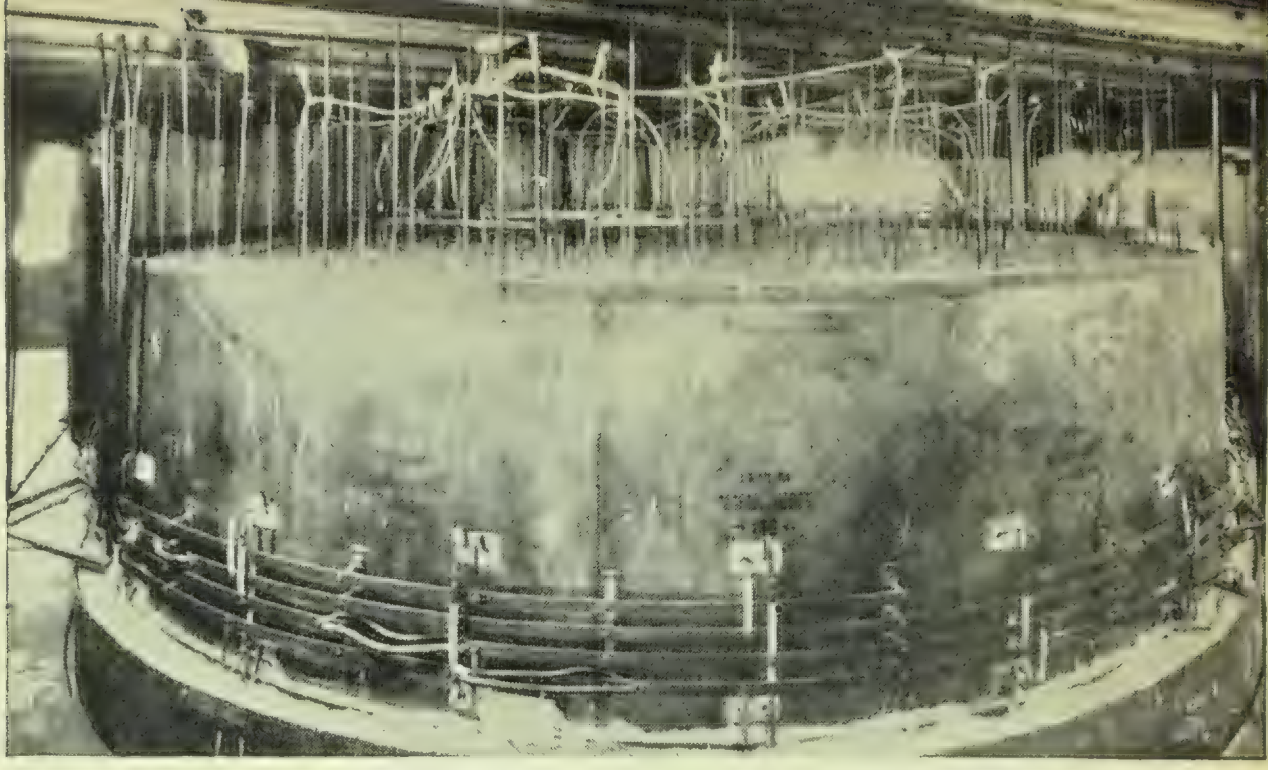

FIG. 34. In this queer-looking container the glass disk for the huge telescope on Mt. Palomar, California, was slowly cooled for more than a year. The disk is 200 inches in diameter and 25 inches thick. It weighs 20 tons. If the hot molten glass had not been slowly cooled, the disk would have cracked as it contracted. (Corning Glass photo)

Now think about another question. Why is one end of a long iron bridge sometimes placed on rollers? At first, you might not believe that this question could be answered by using our principle. You have not studied anything about bridges, but you have found out what heating and cooling do to solids. If you stop and think a minute, you will see that our principle solves this problem.

In most parts of Canada there are great changes in temperature during the year. The change in temperature from a hot day in summer to a cold day in winter may easily be as much as 100 degrees. In an iron bridge 1000 feet long, this change of 100 degrees will make a difference of over five inches in the length of the bridge. You see now why one end must be free to move—why it must be placed on rollers. Some method must be used to allow room for the expansion and contraction of the iron; otherwise, the iron would bend or break.

*Self-Testing Exercises.* 1. Copy the sentences below. Complete each sentence with the word that will make it a true statement.

a) When solids get larger, we say that they ........
b) When solids get smaller, we say that they ........
c) Solids ........ when heated.
d) Solids ........ when cooled.

2. What does a principle of science tell us?
3. How do scientists discover principles of science?
4. Explain how the bottle with the glass stopper (described on page 63) was opened.

*Problems to Solve.* 1. Men employed by a telephone company are stringing wire between poles on a hot summer day. Should they allow a little slack in the wire, or should they stretch it as tightly as possible? Explain.

2. The metal cover of a fruit jar can often be loosened if hot water is poured on the metal. Explain.

3. Figure 32 shows what happened to one concrete road on a very hot day. Why do you think this happened?

4. Why do thin glass tumblers not break so easily as thick glass tumblers when hot water is suddenly poured on them?

5. How can you safely use hot water to wash glassware?

WHAT IS "CHANGE OF STATE"? You have seen that solids are changed in size by heating and cooling. Can you think of another change that takes place when a solid is heated enough? If a cake of ice, which is water in a solid state, is brought into a warm room, it melts. In other words, it changes to a liquid. Water can exist as ice only when the temperature is below freezing. If the air is warmer than this, some of the heat from the air melts the ice. You can see this take place if you add some ice to a glass of water. The water will get much colder, and the ice will melt. The heat from the water melts the ice.

Many other solids besides ice are changed to liquids, too, if they are heated enough. You do not see them in a liquid state very often, because they are seldom heated enough to make them melt. If you will look at Table 5, you will find the *melting point* of some of our common metals. This table tells you just how hot these metals must get before they change from solids to liquids. In this table notice that the melting points are shown in degrees *Fahrenheit* (F.) and also in degrees *centigrade* (C.). The kind of thermometer we use in our homes is a Fahrenheit thermometer. On this thermometer the melting point of ice is 32°. On the centigrade thermometer, which scientists use a great deal in their work, the freezing point is 0°. In the list of science words at the back of this book, you will find "centigrade" ex-

plained more fully. You are also told there how to change Fahrenheit readings to centigrade and centigrade to Fahrenheit.

The kind of change that takes place when ice changes to a liquid is called by the scientist a *change of state*. Now let's see what this means. You have seen that matter, or a material, may

TABLE 5. MELTING POINTS OF SOME COMMON METALS

| METALS | DEGREES FAHRENHEIT | DEGREES CENTIGRADE |
|---|---|---|
| Wood's metal* | 158 | 70 |
| Tin | 450 | 231.9 |
| Lead | 621 | 327 |
| Zinc | 787 | 419.4 |
| Aluminum | 1218 | 658.7 |
| Silver | 1761 | 960.5 |
| Gold | 1945 | 1063 |
| Copper | 1981 | 1083 |
| Iron | 2795 | 1535 |
| Platinum | 3191 | 1755 |

*A mixture made of tin, lead, and other metals.

be in the form of a solid, a liquid, or a gas. Scientists call these the *states* of matter; that is, matter may be in a solid state, a liquid state, or a gaseous state. When a solid changes to a liquid, it thus changes from a solid state to a liquid state. A change of state also takes place when a liquid changes to a solid or a gas, or when a gas changes to a liquid.

Some substances do not have a definite temperature at which they suddenly melt or freeze. Butter, for example, is hard when it is cold. As it is warmed, it becomes softer and softer and finally changes to a liquid if the temperature becomes high enough. Sealing-wax and glass are two other substances that change gradually from solid to a liquid. Glass is easily shaped because it becomes softer and softer as it is heated instead of changing suddenly from a solid to a liquid. Usually it is heated until it is red hot. At this temperature it can easily be shaped by blowing air into it, by pressing it, or by bending it.

*Self-Testing Exercises.* 1. Copy sentences *a* to *d*. Complete each sentence with the word or words that make it a true statement.

*a*) When a solid is heated to its ..........., it changes to a liquid.

b) A change of a solid to a liquid is called ............

c) The melting point of ice is ............° on the Fahrenheit thermometer and ............° on the centigrade thermometer.

d) Substances which melt gradually are ............, ............, and ............

2. What is one characteristic of glass that makes it easy to mold into different shapes?

*Problems to Solve.* 1. On hot days asphalt pavements will show the marks of heels. Explain.

2. Why cannot a solid like ice be shaped by pounding, as copper or iron is shaped?

3. Suppose that butter had a definite melting point just as ice has. How would this affect our ways of using butter?

4. Does the chocolate used in chocolate bars have a definite melting point? Give reasons for your answer.

5. (*a*) Suppose you are in a country where the centigrade thermometer is used, and the thermometer reads 38°. Find what temperature a Fahrenheit thermometer would show. Prove your answer by studying Figure 35. (*b*) On a hot summer day a Fahrenheit thermometer read 95°. Can you find the corresponding reading on the centigrade scale?

6. Find out what makes the valves open in an automatic-sprinkler system for protecting buildings against fire.

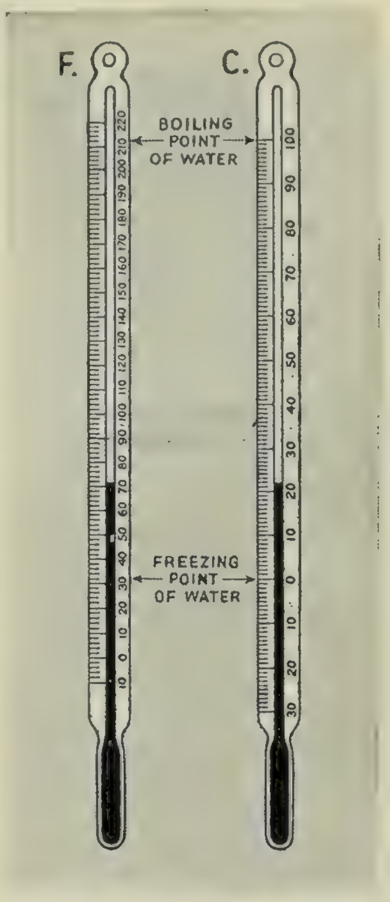


FIG. 35. Centigrade and Fahrenheit thermometers

HOW DO HEATING AND COOLING CHANGE LIQUIDS? Now that you know what happens to solids when they are heated, you can probably guess what will happen when liquids are heated. But, since you are studying science, you cannot be satisfied with guesses when it is possible for you to find out by experimenting just what does happen.

*Experiment 8.* HOW DO HEATING AND COOLING CHANGE THE VOLUME OF LIQUIDS? (*a*) Fit a test-tube with a cork. Bore a hole in the cork. Insert a twelve-inch piece of glass tubing of the smallest diameter you can find. Fill the test-tube with colored water or red ink. Insert the cork and tubing in the test-tube. Have enough liquid in the test-tube

so that it will go up into the tubing a little way above the cork. Tie a string around the tubing at the level of the liquid (Figure 36). Heat the test-tube gently. What happens to the level of the liquid? How can you explain what happens?

b) Place the test-tube in a jar of cold water. What happens to the level of the liquid in the test-tube? How can you explain what happens to the liquid?

FIG. 36. Apparatus for Experiment 8

For many years you have been using a thermometer to tell you how hot or cold it is. You see the mercury or colored liquid go down, and you know that the air is getting colder. You see the liquid rise, and you know that it is getting warmer. Of course, what happens is that the mercury in the bulb expands when heated and forces mercury up in the tube. When the air gets colder, the mercury in the bulb becomes cooler, contracts, and the mercury in the tube moves down. Now you can explain why the water overflowed from the kettle when it was heated.

Here is another everyday happening that you can explain when you know how heat affects liquids. To keep your automobile engine from becoming overheated, you try to have the radiator nearly full of water. Usually the water is cold when you pour it in. If you fill the radiator until it is level, and then drive the car until the water gets very hot, you will find that water is coming out on the hood or pouring out from a pipe beneath the car. Perhaps you have noticed the directions on a can of anti-freeze solution used in automobile radiators. The directions say, "Do *not* fill the radiator entirely full of water. If you do, some of the anti-freeze solution will be lost as you drive." You can see now the reason for these directions.

Heating and cooling can also be used to change the state of a liquid. You have seen many examples of what happens to liquids when they are cooled. Liquid water changes to ice at

32° Fahrenheit, or 0° centigrade. Every liquid can be changed to a solid if it is cooled enough. The temperature at which a liquid changes to a solid is called its *freezing point*. The freezing point of a substance is the same as its melting point. Some liquids need to be cooled a great deal before they will change to solids. Such a liquid as alcohol has to be cooled to nearly 200° below zero Fahrenheit to freeze it. Mercury can be changed to a solid if it is cooled to about 38° below zero Fahrenheit. At that temperature it freezes into such a hard lump that it can be used to drive a nail.

You already know, of course, that when water is heated hot enough, it will boil and change to steam. Steam is water in a gaseous state. There is one fact about boiling, however, that you probably do not know. Experiment 9 will show you what it is.

FIG. 37. Apparatus for Experiment 9

*Experiment* 9. HOW DOES WATER BOIL? Pour some water into a tall beaker and place it over a wire gauze. Put a thermometer in the beaker. Place a burner under the gauze and light the gas. In a short time small bubbles appear. These are bubbles of air. Continue to heat the water until very large bubbles are formed on the surface of the water. These bubbles are steam. Take the temperature of the water. Continue to heat the water. Can you get it any hotter? If you can do so, put another lighted burner under the beaker. What effect, if any, does this have upon the rate at which the water is boiling and upon the temperature of the water?

If water or any other liquid is heated hot enough, it will boil. When a liquid boils, it changes to a gas, and the gas forms bubbles that rise to the surface and break. When the bubbles break, the gas passes off into the air. Strangely enough, in a pan that is open to the air, a liquid cannot be heated any hotter than its boiling point. If boiling water is heated more, it merely boils faster. Its temperature stays the same. Table 6 gives the

boiling points of some common liquids. From what the table tells you, see if you can explain why alcohol disappears from the radiator of an automobile quicker than water disappears. Would

TABLE 6. Boiling Points of Some Common Liquids

| LIQUID | DEGREES FAHRENHEIT | DEGREES CENTIGRADE |
|---|---|---|
| Ether | 93 | 34 |
| Carbona | 171 | 77 |
| Alcohol | 172 | 78 |
| Water | 212 | 100 |
| Turpentine | 318 | 159 |
| Glycerine | 556 | 291 |
| Mercury | 675 | 357 |

a mixture of water and glycerine boil more quickly or less quickly than water? Work out an experiment to find the answer to this question.

From what you have just learned you might think that liquids have to be heated to their boiling temperature before they can change to gases. This, however, is not true. For example, after a rain the little puddles of water on the pavements and sidewalks disappear in a few hours. Wet clothes hung out on the line soon dry. Water left in an open pan finally disappears. You see these things happen so often that you pay little attention to them. Do you ever wonder what becomes of the water? It might soak into the pavement or drip from the wet clothes. Some of it does. But you know that water cannot soak through a glass tumbler or an aluminum pan. We say that the water "dries up," and we know that it has changed to a gas and mixed with the air. Before you finish this unit, you will see by an experiment that there really is water in the air.

Scientists have a word to describe the changing of a liquid to a gas. The word is *evaporation*. You can say that a liquid changes to a gas, or you can say that a liquid *evaporates*. And one of the problems that scientists have studied is that of finding how and why liquids evaporate, because they have needed to evaporate liquids for many different purposes. You can do an experiment that will show you an important principle of evaporation.

*Experiment* 10. DOES HEATING MAKE WATER EVAPORATE MORE QUICKLY? Dip a dish, bottle, or glass tumbler into some cold water. Dip another dish into some very hot water. Find out which dish dries the quicker. Does heating speed up or slow down the rate of evaporation of the water?

Water is always changing from a liquid to a gas at any temperature, that is, no matter how hot or how cold it is. But the experiment has shown you that the speed at which it changes to a gas depends upon its temperature. The hotter the water is, the faster it changes. The colder it is, the slower it changes.

In Experiment 10 you used water as an example of a liquid. Perhaps you wonder if other liquids also evaporate. Yes, they do, but they do not change at the same speed as water. Gasoline, for example, evaporates much more quickly than water. Ether, a drug used to put a person to sleep during an operation, evaporates much more quickly than gasoline. If a small quantity of ether is poured on the hand, the liquid will disappear almost instantly. Heavy, thick liquids, such as oil, evaporate more slowly than water. Different liquids evaporate at different speeds.

Now let us see what we have learned about evaporation: (1) Liquids change to gases, that is, evaporate, at all temperatures. (2) Heat increases the speed of evaporation. (3) Different liquids evaporate at different rates.

You can use these ideas about evaporation to explain many changes that take place every day in the world around you. Perhaps you have noticed that the grass is covered with dew in the early morning on a summer day. Shortly after the sun rises, the dew disappears. What has become of it? You can answer this question by remembering what you have learned. Because it is cool in the early morning, evaporation takes place very slowly; but when the sun comes up, the grass and dew are warmed, and the speed of evaporation is increased. The dew soon disappears into the air. Perhaps you have cleaned grease from your clothing by rubbing the spot with gasoline. You have seen that the spot dries almost immediately—much more quickly than a spot of water dries. What you have learned tells you that you used a liquid that evaporates very quickly. The spot was soon dry because the liquid quickly passed into the air as a gas.

*Self-Testing Exercises.* 1. Copy the sentences below. Complete each sentence with the word or words that make it a true statement.

a) Liquids ............ when heated.
b) Liquids ............ when cooled.
c) If a liquid is cooled sufficiently, it changes to a ............
d) The freezing point of a substance is the same as its ............
e) When bubbles of steam break through the surface of water, we say the water is ............
f) In an open pan water can be heated only to ............° F.
g) If the heat is increased after water is boiling, the temperature (*remains the same*) (*increases*) (*decreases*), and the water boils .........
h) Water disappears when placed in an open saucer. It changes from a ............ to a ............
i) Evaporation is the process in which a ............ changes to a ............
j) Liquids are (*sometimes*) (*always*) evaporating.
k) Different liquids evaporate at (*the same rate*) (*different rates*).
l) Windows dry after a rain because (*the water all runs off*) (*some of the water runs off and some of it evaporates*).
m) Evaporation usually takes place more rapidly (*at night*) (*during the daytime*).
n) The surface of the soil is usually drier than the soil a few inches under the surface. The explanation for this is that (*the water sinks into the soil*) (*the water on the surface evaporates*).
o) Evaporation will usually take place more rapidly on a warm day than on a cold day. True or false? ............

*Problems to Solve.* 1. When fruit is canned, the glass jar is usually filled to the top with very hot fruit and syrup. But when the jar is examined later on, it is found to be no longer full. Explain.

2. If a fountain-pen is filled with ink and carried on a very hot day, it will sometimes leak. Explain.

3. If you are boiling potatoes, how should the gas be regulated so as to cook the potatoes in the shortest possible time with the least amount of fuel? Explain your answer.

4. A milk bottle with only a little milk in it was taken from a very cold refrigerator and placed on a kitchen table. Soon there was a "fizzing" sound, and bubbles began to come out around the paper cap of the bottle. Explain why.

5. Why must a person add more water to the radiator of an automobile if he is taking a long trip at a high speed than if he is driving slowly for a short distance?

6. Why do candies like fudge or nougat become very hard and dry if they are exposed to the air for some time? How might you prevent this?

7. Why should you always screw on tightly the lid of a bottle of paste?

8. Pop-corn kernels contain a great deal of water. When they are heated, they pop. What is a probable explanation for the "popping"?

HOW DO HEATING AND COOLING CHANGE GASES? Before you read the study material that follows, you might try to *predict* how heating and cooling change gases. "To predict" means to tell what you think will happen in a certain situation before it has happened.

A scientist is always trying to predict what will happen. He observes something happen, and he notices carefully the conditions under which it happens. Then he uses what he has learned to predict what will happen in other situations like the one he has observed. You have seen that solids and liquids expand when heated and contract when cooled. You have also seen that when liquids and gases are heated or cooled enough, a change of state takes place in them. Now what do you suppose will happen to gases if you heat or cool them?

FIG. 38. Apparatus for Experiment 11a

*Experiment 11.* WHAT HAPPENS WHEN GASES ARE HEATED AND COOLED? (*a*) Use the test-tube, cork, and glass tubing that you used in Experiment 8. Have the inside of the test-tube clean and dry. Place the end of the glass tubing in some colored water (Figure 38) and heat the test-tube. Notice what happens to the colored water. How do you explain this?

Allow the test-tube to cool. What happens? Pour some cold water on the test-tube. What happens? What is your conclusion? Was your prediction correct?

*b*) Steam, as you know, is the invisible gas formed when water boils. Let us see what happens when steam is cooled. First, we will make some steam by heating water in a flask. To keep the steam from being lost in the air, we will use a stopper with a glass delivery tube in it (Figure 39). Then we will place a test-tube under the delivery tube and pass the steam into the test-tube. Can you see the steam? Does the steam change to a liquid? Now place the test-tube in a beaker of cold water and pass the steam into the tube of water. Does the steam change to a liquid now?

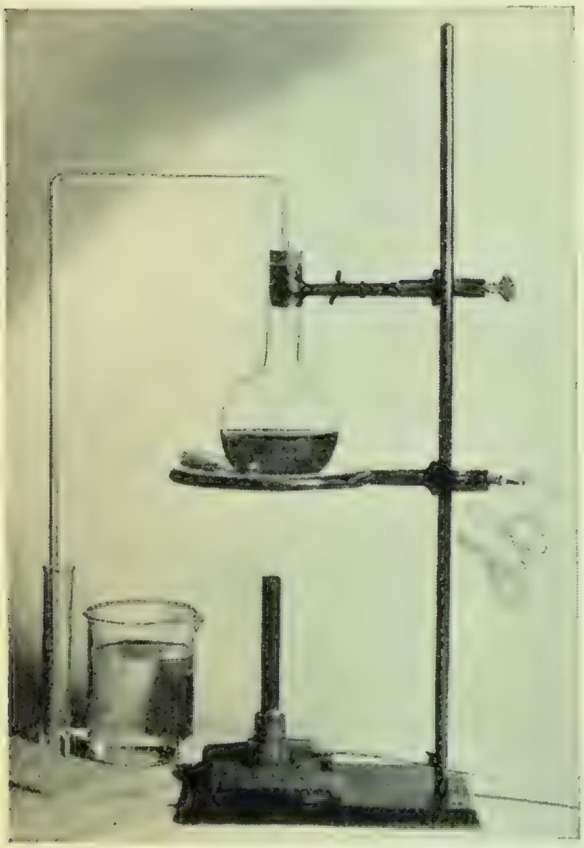

FIG. 39. Experiment 11*b*

Now that you have learned that gases, too, expand when heated and contract when cooled, you will find that this principle, like the others you have learned, will help you explain some common happenings. When your mother makes an angel-food cake, she beats the whites of eggs. Beating the eggs traps air in them, and the beaten eggs become fluffy and white. Then the eggs are mixed with the flour and other materials and placed in the oven.

Now why does this wet mass swell up into a light, tasty cake? You know a science principle that will tell you. The air in the beaten eggs and the gas from the baking powder expand when heated in the oven, and the cake "rises." When you cut the cake, you can see the holes made in it by the expanding air bubbles.

If you have taken an automobile trip on a hot day in summer, you may have seen your father let some air out of the tires. Why did he do this? When you drive over a hot concrete road, the tires get very hot, and the air inside expands. Since the air cannot get out of the tires, it pushes against the walls of the tires with greater force. If the tires are blown up very hard when they are cool, the extra pressure caused by the heat may burst them.

And now let us see what happens when steam is cooled. You remember that water boils when it is heated to 212° Fahrenheit

or 100° centigrade. As it boils, it turns into bubbles of steam that pass into the air. When this steam is cooled below 212° Fahrenheit, it *condenses*. Now we can explain the white cloud that appears above the spout of a tea-kettle of boiling water. As the steam comes from the spout, you cannot see it. A short distance from the spout, the steam strikes the cool air around the kettle. The steam is cooled and condenses into tiny drops of water. The white cloud is made of millions of tiny drops of water floating in the air. You have seen steam condense around the smoke-stack of a locomotive. Some people call the white cloud steam. Are they correct?

Other gases may be changed to liquids, too, if they are cooled enough. Even air can be changed to a liquid that looks like water. To do this, the air has to be cooled to a temperature of more than 200° below zero Fahrenheit. If you place a glass of liquid air on the table, it will immediately begin to boil furiously and will quickly disappear. In order to remain in a liquid state, the air must be kept at a temperature of 190° below zero centigrade.

Have you ever noticed that drops of water sometimes collect on the windows inside of the house? Sometimes these drops are very small and merely form a film over the glass. But you can see that the film is water if you run your finger through it. Where does this water come from? And why does it form on the glass? You have already learned that water is constantly changing to a gas and mixing with the air. Air can hold only a certain amount of water vapor at a certain temperature. Hot air can hold a great deal of water vapor; cold air is able to hold much less water vapor.

Now let us suppose that water has been evaporating into air, and that the air has taken up all the water vapor it can hold. What do you suppose will happen if the air is cooled? Some of the water vapor will have to come out of the air. When it comes out of the air, it condenses into liquid water. Water on the window-pane is formed in this way. The glass gets cold, and it cools the air that comes in contact with it. The result is that some of the water vapor in the air condenses on the glass, as you can see from Experiment 12.

*Experiment* 12. HOW CAN WATER VAPOR FROM THE AIR BE CONDENSED? Obtain a bright tin cup. Fill it half full of cold water. Watch the outside of the cup. Do you see a film of moisture forming on it? If not, add a little ice and stir the mixture of ice and water. Keep on adding ice until a film of moisture appears. It may be necessary to add salt, also, to make the ice melt more rapidly.

If the air has a large amount of water vapor in it, it need be cooled only a few degrees to cause condensation to take place. If only a small amount of water vapor is present, the air must be cooled many degrees before condensation takes place. You have probably blown your breath on a cold window-pane to see the film of water collect on the glass. Do you think that your breath contains a large amount of water vapor or a small amount?

*Self-Testing Exercises.* Copy the sentences below and choose the correct word or words for each sentence. contract

1. Gases expand when heated and contract when cooled.
2. To change a gas to a liquid, the gas is cooled. or compressed.
3. The white cloud around the spout of a tea-kettle of boiling water is made of (*steam*) (*tiny drops of liquid water*).
4. Cold air can hold (*more*) (*less*) water vapor than hot air.
5. Water vapor will condense from air less if the air is (*cooled*) (*warmed*) enough.
6. If air has a large amount of water vapor in it, it must be cooled (*more*) (*less*) than if it contains only a small amount of water vapor.

*Problems to Solve.* 1. A football is pumped up in a warm room and is then used outdoors, where the temperature is about freezing. Will it become softer or harder when it is taken outdoors? Explain.

2. When a pitcher of ice water is brought into a warm room in the summer, drops of water usually form on the pitcher. Explain.

3. When a person wearing glasses comes into a warm room from the cold outdoors, a film often forms on the glasses. Explain.

4. On very cold days we often "see our breath." What is it that we actually see? moisture of body from lungs.

5. Explain why automobile windshields may become covered with frost in cold weather. condensed moisture from passenger

6. An automobile tire manufacturer advised automobile drivers as follows: "When you are driving long distances at high speeds on hot days, stop once in a while and have your tire pressures checked. You may save yourself from a serious accident." Explain this advice.

FIG. 40. The molecules in a solid are usually a little closer together than those in a liquid. And the molecules in a liquid are much closer together than those in a gas.

## ¶ 2. How can we explain how heat changes matter?

HOW DOES THE MOLECULAR THEORY EXPLAIN CHANGE OF STATE? Do you remember the molecular theory—the theory that everything is made of tiny bits of matter called molecules? Do you remember also that these tiny bits of matter are constantly moving and that there are spaces between them? Now let us see whether this theory will explain why solids, liquids, and gases get larger when they are heated. If the theory is a good one, it ought to tell us why matter acts the way it does when it is heated.

Scientists have actually been able to prove that the molecules of a material move faster when the material is heated. The theory is that as they move faster, they bump into each other harder. Therefore they knock each other farther apart. Of course, when this happens, the material expands. When the material is cooled, the molecules move more slowly, get closer together, and the material contracts. Perhaps this will be clearer to you if you imagine a swarm of bees all bunched on a limb. They are crawling slowly over each other in an almost solid mass. You come up and make them angry. They begin to fly round and round, faster and faster. To do this, they need room, and the swarm spreads out until it is many feet across.

We can also explain how heating changes materials from one state to another. When solids are heated, the speed of the

FIG. 41. From the first pan, containing water, a few molecules gradually fly off into the air. From the second pan, containing warm water, more molecules escape. When water is hot, as in the third pan, many molecules escape rapidly.

molecules is increased. The molecules knock each other farther apart, and the solid changes to a liquid. When a liquid is heated, the molecules move still faster and knock each other still farther apart, and the liquid changes to a gas. When gases are cooled, the molecules move closer together, and the gas changes to a liquid. When a liquid is cooled, the molecules move still closer together, and the liquid changes to a solid.

HOW DOES THE MOLECULAR THEORY EXPLAIN EVAPORATION? It is much easier to understand how evaporation of liquids takes place if we use the molecular theory. We found, you remember, (1) that evaporation takes place at all times, (2) that the speed of evaporation is increased by heating the liquid, and (3) that liquids can be heated only to a certain temperature in an open vessel. These are all facts that you have observed in experiments. Now let us see if we can explain these facts by the molecular theory.

You remember that the molecules of a liquid are moving at high speed. If you could see the molecules in a dish of water, you would see billions of tiny particles darting in all directions. There are so many of them that collisions are constantly taking place. Occasionally a molecule that is moving up toward the surface of the water manages to escape a collision, and, because it is going so fast, it shoots out into the air. This is what happens when a liquid evaporates. The molecules simply escape from the liquid and fly off into the air or the surrounding space. When the liquid is heated, the molecules move faster. The result is that

more molecules fly out into the air. This, of course, means that the water evaporates more rapidly when it is heated. And this is exactly what you found in your experiment.

To explain how boiling takes place is a little more difficult. You will remember that the molecules of a liquid knock each other farther apart when the liquid is heated. The hotter the liquid gets, the harder the molecules hit each other and the farther they knock each other apart. When the temperature reaches the boiling point, some of the molecules knock each other so far apart that they form a bubble of gaseous water, or steam, in the water. This bubble rises to the top of the water, and the molecules of steam mix with the air. If more heat is applied after a liquid begins to boil, more bubbles form, and the change to steam is made more rapidly. In an open pan a liquid cannot be heated higher than its boiling point because the extra heat simply makes the liquid change to a gas more rapidly.

*Self-Testing Exercises.* Copy the sentences below, and choose the correct word or words for each blank space.

1. Molecules are (*closer together*) (*farther apart*) in liquids than in solids.
2. Molecules are (*closer together*) (*farther apart*) in gases than in liquids.
3. When gases are cooled, the molecules move (*closer together*) (*farther apart*), and the gas changes to a liquid.
4. Evaporation takes place when a molecule [illegible] from the surface of a liquid.
5. At the boiling point, the space between the molecules becomes so great that some of the water is changed to a gas.
6. If more heat is added after a liquid is boiling, the added heat is used to change the liquid to a gas at a faster speed.

*Problems to Solve.* 1. Make a drawing of a bottle of air. Use dots to represent the molecules. Now draw another bottle and show the molecules after the bottle has been heated.

2. Explain why clothes will dry faster in front of a hot stove or in the sunshine than they will in a cool place.

3. Explain, in terms of molecules, what makes vapor condense from the air.

4. Are there as many molecules of water in a quart of water at a temperature of 80° F. as there are in a quart at 60° F.? Explain.


FIG. 42. Apparatus for Experiment 13

## 3. How can we change one kind of material into another kind of material?

YOU HAVE MADE A WIRE LONGER simply by heating it; you have used mercury in a tube to tell how hot or cold things are; you have changed a liquid into an invisible gas; and you have made solid materials disappear in a glass of water. If you travelled to some unexplored place, you could probably set yourself up as a magician among the savage tribes who might be living there.

But there are still more "magic tricks" that can be done with materials. So far you have not learned how to change one material into another kind of material. When you freeze liquid water, you are merely changing water from a liquid to a solid. When you change liquid water to steam, the steam is still water; it has only been changed from a liquid to a gas. When you dissolve sugar in water, you have not changed the sugar into a new material. It is still sugar. When you heat iron, it expands; when you cool it, it contracts. You have changed materials in some ways, but you have not changed them into new materials. In this problem you are going to learn how to change a material into another kind of material.

WHAT HAPPENS TO THE CHARACTERISTICS OF A SUBSTANCE DURING A CHEMICAL CHANGE? If you have ever made a cake, dyed a dress, taken a photograph, lighted a fire, or eaten

FIG. 43. Experiment 14

a piece of bread, you caused a *chemical change*. You also have seen the results of many chemical changes. When food spoils, fountain-pen ink changes color, newly laid concrete roads become hard, the leaves on the trees change color, or a piece of wood decays, chemical changes are going on. It does not seem possible that the chemical changes in all of those different materials would be alike in some ways. But they are alike, as you will soon see. To discover what happens to materials when a chemical change takes place, let us first do a few experiments.

*Experiment* 13. WHAT HAPPENS WHEN WOOD IS HEATED? Get a piece of wood about two inches long and small enough to go inside a test-tube. Fit a cork to the test-tube. Bore a hole in the cork and in the hole put a piece of glass tubing about three inches long. Put the cork in the test-tube and clamp the test-tube on a ring stand. Heat the tube strongly, moving the flame around so that all the wood is heated but the glass does not melt.

What do you see in the test-tube? Touch a flame quickly to the end of the glass tube. What happens? Heat the wood until no more gas is made. What is left in the test-tube? Take the material out and examine it.

*Experiment* 14. WHAT HAPPENS WHEN SULPHUR AND IRON ARE HEATED TOGETHER? (*a*) Mix together in a dish one-third of a test-tube of iron powder and one-third of a test-tube of powdered sulphur.

Pour some of the mixture into a test-tube of water and shake it thoroughly. Allow it to stand for awhile. What is in the bottom of your tube? What settles last?

*b*) Pour the remainder of the mixture into a test-tube and heat until the sulphur melts and a red glow spreads all through the mass. Break the test-tube to remove the material; then break the material into small pieces. Does it look like iron or sulphur? Pour some of the material into a test-tube of water and shake it thoroughly. Allow it to stand for awhile. How do you explain what happened in this experiment?

In each of these experiments a chemical change took place. To find what happened, let us first study the characteristics of the materials before and after the chemical change.

The wood in Experiment 13 had certain characteristics. It was white or yellowish white; it could be cut with a knife; it had a certain weight; and it would burn with a flame. When it was heated, whitish-colored fumes were given off. Left in the tube was a black solid called *charcoal*. This black material was mostly the element carbon. As a result of heating, the wood changed into two kinds of materials. It changed into gases and carbon. Neither of these materials has the same characteristics as the wood. The wood is no longer wood; it has been changed into something else.

This is what always happens when a chemical change takes place. The material becomes a different material. Or it may become two or three materials, all different from the first material. When a material is broken up into two or more materials, the chemist says that the material has *decomposed*. He calls the process *decomposition*. In Experiment 13 the piece of wood decomposed when it was heated. A great deal of one element (carbon) was left in the test-tube. However, the gases that went away into the air or burned at the mouth of the test-tube were compounds, as you will learn in the next unit. From this you can see that a material may decompose into elements, or into compounds, or into both elements and compounds.

Not all compounds can be decomposed by heating them with an ordinary burner. If you will stop to think, you will know that this is true. Water is a compound made of hydrogen and oxygen ($H_2O$). When you heat water, it merely changes into steam; it does not decompose. If you cool the steam, it changes back into water again. But water can be decomposed by passing a current of electricity through it and in several other ways. Chemists have many different methods of decomposing compounds. If they did not know how to decompose compounds, we would not have many of the substances and materials that we use every day.

Now let us see what happened in the experiment with iron and sulphur. When the powdered iron and sulphur were just

FIG. 44. When sulphuric acid is poured over sugar, it removes water (hydrogen and oxygen) from the sugar, leaving black carbon. The heat and water that are produced form steam, which puffs the carbon into a spongy mass.

mixed together, they could be easily separated by putting the mixture in water. The heavy iron particles quickly settled to the bottom. Then the lighter sulphur particles settled on top of the iron. No change had taken place in the iron and sulphur. This we know because their characteristics were just the same as they were before the materials were mixed together.

After they were heated together, they could no longer be separated by mixing with water. A chemical change had taken place. The iron and sulphur had *combined,* or gone together, to form a new material. This new material that was made by *chemical combination* is called iron sulphide. It is a compound of iron and sulphur. This new material is not like iron. Neither is it like sulphur. As a result of the chemical change, a new material has been formed. This new material is different from either of the materials of which it is made.

But you must not get the idea that any two elements can be combined to form a new compound. For example, you cannot make copper and gold combine to form a compound. It has taken chemists hundreds of years to discover what elements will combine with each other. You would have to study chemistry to know what elements may be combined and how to make them combine.

Now let us recall two other chemical changes that you have studied. You remember that mercuric oxide changed into mercury and oxygen when it was heated, or we may say that it was decomposed into mercury and oxygen. And you remember that

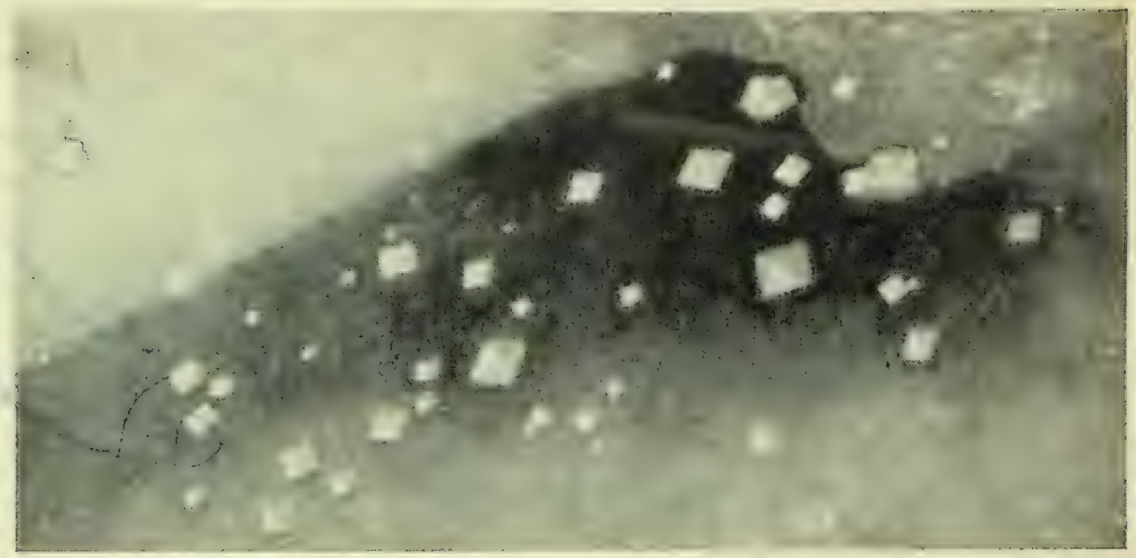

FIG. 45. This picture shows a solution of salt water being evaporated in open pans over steam pipes. Salt crystals are forming on the surface of the hot water. Is a chemical change taking place? Why do you answer as you do? (International Salt Co. photo)

oxygen and hydrogen can be put together, or combined, by the chemist to make water. All of these chemical changes are alike in one way: The material or materials that are formed are different from the materials you started with. You know that this is true because these new materials have different characteristics from the materials you started with.

Now let us see what you have learned about the way materials are made. All the materials in the world are made of elements. Some materials contain only one element. In some materials the elements are combined into a compound. If a material contains only one element or only one compound, the chemist calls the material *pure*. Iron and iron rust are pure materials. One of them is a pure element, and one is a pure compound. Can you tell which is which? Sugar is also a pure compound. Most of the substances around us, such as air, soil, and milk, are not pure substances. They are neither pure elements nor pure compounds. They are mixtures of elements, of compounds, and of elements and compounds.

*Self-Testing Exercises.* 1. How can you tell when a chemical change has taken place?

2. How do you know that a chemical change took place when wood was heated? When iron and sulphur were heated? When mercuric oxide was heated?

3. Explain how you know that the chemical changes in the first paragraph on page 83 are really chemical changes.

4. Make as long a list as you can of other chemical changes that are going on around you. In each case, explain how you know that it is a chemical change.

5. What does a chemist mean when he says that a material decomposes? What kinds of substances can be decomposed?

6. What does a chemist mean when he says that two elements combine? What do we call the kind of substance that is produced when two elements combine?

7. What is meant by a pure substance?

8. When you stir sugar and sand together, do you make a mixture or a compound? Explain why you think your answer is right.

*Problems to Solve.* 1. Below you will find listed a number of changes that take place in materials. Which ones do you believe are chemical changes? Which ones are not chemical changes? To answer these questions you must get clearly in mind what happens when a chemical change takes place. Then you must study each of the changes to see if it is a chemical change.

F a) Butter melts when it is heated.
C b) Matches take fire when rubbed on a rough surface.
F c) Water freezes if cooled below 32° F.
F d) Rock is often crushed into small pieces.
C e) Green leaves become yellow when kept in the dark.
C f) Meat decays if it is not kept properly.
F C g) Gasoline evaporates if left in an open dish.
C h) A green coating forms on copper roofs.
F i) Aluminum may be pressed into thin sheets.
C j) A fire-cracker explodes when it is lighted.
C k) Camera films are spoiled if exposed to light.
l) Sugar dissolves in water.
F m) The whites of eggs become fluffy when beaten.
C n) When colored clothes are washed in water containing ammonia, they often fade.
o) A silver spoon that is used to stir scrambled eggs will become black if it is not cleaned.
C p) Straw hats that have become yellow can be made whiter by the use of lemon juice.

2. Richard was playing with his new chemistry set. He poured some clear liquid into a test-tube that contained some white powder.

The solution in the tube became very hot and gave off a bad odor. A dark mass of solid material settled to the bottom of the test-tube. Do you think that he had caused a chemical change? Tell why you think so.

3. Iron rust contains oxygen and iron. Why can you not use a magnet to separate the iron from the oxygen?

4. Plants use chemicals from the air, soil, and water to make sugar. What kind of chemical change is this?

5. Table salt is a common food. It is composed of sodium, which will cause a sore if placed on the tongue, and a poisonous gas, chlorine. Explain why we can safely use the compound made from these substances.

6. If a candle flame is held close to a piece of glass, carbon will form on the glass. What kind of chemical change has taken place? Tell how you know.

7. When a tree decays, part of it changes to a gas that mixes with air, and part of it remains in the ground as minerals. What kind of change is this?

HOW CAN WE CONTROL CHEMICAL CHANGES? Perhaps you have seen labels like these on boxes or bottles: "Keep in a cool, dark place." "Do not use near an open flame." "Keep in a dry place." Have you ever seen this caution on a box of camera film: "Do not open in the light"? Why do you suppose these statements are printed on the labels? They are put there so that you will know how to keep the materials from spoiling. And if you do not follow directions, they will spoil because harmful chemical changes will take place. What are some of the things that make chemical changes take place?

You have already seen that you can make chemical changes take place by heating materials. When iron and sulphur were heated together in Experiment 14, iron sulphide was produced. The iron and the sulphur did not combine until they were heated. We use heat to make a chemical change when we strike a match. When the match is rubbed on a rough surface, there is *friction* between the two rubbing surfaces. This friction heats the match, and the heat causes a chemical change. Chemical changes are more rapid when the materials are heated.

Many chemical changes will not take place at all unless the materials are heated to a high temperature. For example, iron

Fig. 46. In the upper beaker is a mixture of two white powders. Mixing them does not change them until they are poured into water. Then, as shown in the beaker at the right, something very definite happens. (See Experiment 15.)

ore as it is mined from the earth is a compound of iron and oxygen. To get pure iron, it is necessary to separate the oxygen from the iron. First, coke (carbon) is mixed with the iron ore. If the iron ore and coke are merely mixed together, nothing happens. But if the mixture is heated to a high temperature in a big furnace, the coke takes the oxygen away from the iron. Glass is made of soda, sand, and limestone. When these materials are heated to a high enough temperature, they melt, mix together, and go through chemical changes. These chemical changes turn them into the transparent glass that we use for windows, tumblers, and other articles.

The following experiment will show you another way of making chemical changes take place.

*Experiment* 15. CAN WE BRING ABOUT CHEMICAL CHANGES BY DISSOLVING SUBSTANCES? Mix a half teaspoonful of citric-acid crystals and a half teaspoonful of baking-soda. Be sure to keep the mixture dry. Does any change in these chemicals take place? Pour the mixture into a half test-tube of water. Does a chemical change take place? How can you tell? Did dissolving the chemicals help the change to take place?

So long as the citric acid and the baking-soda are kept dry, no chemical action takes place. When they are mixed with water, a gas (carbon dioxide) is made, which shows that a

FIG. 47. Chemical changes caused by light plus other changes caused by the *developing* solution made this negative of a photograph. A *fixing* solution stopped further chemical change when the film was developed satisfactorily.

chemical change has taken place. Water helps many chemical changes take place.

*Experiment 16.* ARE CHEMICAL CHANGES BROUGHT ABOUT BY LIGHT? Dissolve some silver nitrate in water. Fill two test-tubes about one-fourth full of the solution. Keep one tube in a dark place. Put the second tube in the bright sunlight for several minutes. Watch the solution in the second tube carefully during this time. Is there any change in the appearance of the chemical? Take the tube out of the dark place and compare it with the tube that has been in the sunlight. Is there any difference in their appearance? If so, what do you think caused the change?

In this experiment the light causes the silver nitrate to turn dark. Something like this happens when you take a picture with a camera. The film is a sheet of celluloid covered with a thin coating of a chemical that is easily changed by light. When you open the shutter of the camera for an instant, light strikes the film and makes a chemical change in it. Another example of chemical change caused by light is a blue-print. Place a coin on some blue-print paper and put it in sunlight for a short time. Then wash the paper in water. The part that was in the light will be blue; the part under the coin will stay white.

Many of the materials that we need are constantly spoiling because we cannot or do not stop chemical changes in them. Foods decay, iron and steel machinery rusts, carpets and furniture upholstering fade, and rubber loses its elasticity. Hundreds of scientists today are working at the problem of finding ways to

stop chemical changes. Experiment 17 will show you one method of preventing a chemical change.

*Experiment 17.* HOW MAY ONE KIND OF CHEMICAL CHANGE BE PREVENTED? Dip half of a piece of bright new iron into paint. (A large nail will do.) When the paint has dried thoroughly, put the piece of iron into a glass jar. Put a small sponge or a piece of cloth soaked with water into the jar with the iron. Seal the cover tightly on the jar. Allow the jar to stand for several days. What part of the iron is covered with rust? From what was the rust formed? Scrape the paint from the part of the iron that is coated. Did the part of the iron under the paint rust? Explain.

Now you see why bridges, fences, and other objects made of iron are painted. If they are not painted, the oxygen in the air will combine with the iron and form iron oxide, or rust. The chemist knows this; so he looks for something to keep the oxygen in the air from touching the iron. The material he uses must not combine with the iron, either. Paint, he has found, does not change the iron, and it does keep away the oxygen. Oil will do the same thing. If tools are not often used, it is a good plan to wipe them with an oily rag when they are put away. If you do not want chemical changes to take place, you can sometimes stop the changes by keeping materials away from each other.

You can also understand why some bottles and boxes are labelled "Keep in a dark place." Light would cause a harmful chemical change to take place. Since many of us are careless, our chemicals are often put in dark-colored bottles to keep out the light. Have you ever noticed that "peroxide" (hydrogen peroxide, $H_2O_2$) is sold in brown bottles? When hydrogen peroxide is left in a strong light, it separates into oxygen and water. If a bottle is labelled "Keep in a cool place," you know that chemical changes will take place if the material gets too warm.

*Self-Testing Exercises.* 1. Describe three ways of making chemical changes take place.

2. When you light a gas stove or a wood fire, which method of starting a chemical change are you using? Heat,

3. (*a*) Name all the ways that are given in this problem for preventing chemical changes. (*b*) Which of these methods have you used? (a) 1- Paint - protect house outside..
2- Teeth Decay -
3-

*Problems to Solve.* 1. If you examine books that have been kept in cases for several years, you will find that the backs of the books are not as bright colored as the sides. Explain. posure to sun and air.

2. When a picture is taken off a wall, the paper or paint back of the picture is usually darker or lighter than the rest of the wall. Explain.

3. What happens when you over-expose a camera film? When you under-expose it?

4. When colored clothes are washed, it is much better to dry them in the shade. Why?

5. You can buy prepared pancake flour in a store. Why do you suppose it must be kept dry?

6. Why does food turn black if it is left on a hot stove too long?

7. Why should milk usually be kept cold?

8. Find out why aluminum paint is so often used on metal structures such as water towers and pipes.

9. Find out why chromium is used on such metal parts of automobiles as radiators and hub caps.

10. What is "stainless" steel and why was it developed?

## ¶ 4. How do scientists explain chemical change?

WHAT ARE MOLECULES MADE OF? You already know that a substance, such as water, is made of molecules. A molecule is the smallest particle of water that can exist. The formula for water ($H_2O$) tells us that water is made of two elements, hydrogen and oxygen. Since each molecule of water is made of two elements, we know that there must be particles even smaller than the molecule. These particles are called *atoms*. The small number that you sometimes find after the symbol of an element shows the number of atoms of that element in the compound. Thus the formula for water shows you that each molecule of water contains two atoms of hydrogen and one atom of oxygen. Experiments have shown that some elements have one atom in a molecule; others have two atoms. Elements that are gases, such as hydrogen, oxygen, and nitrogen, have two atoms in a molecule. A molecule of any compound, of course, will always have two or more atoms in a molecule, because a compound always contains two or more elements.

When a chemical change takes place, there is always a change

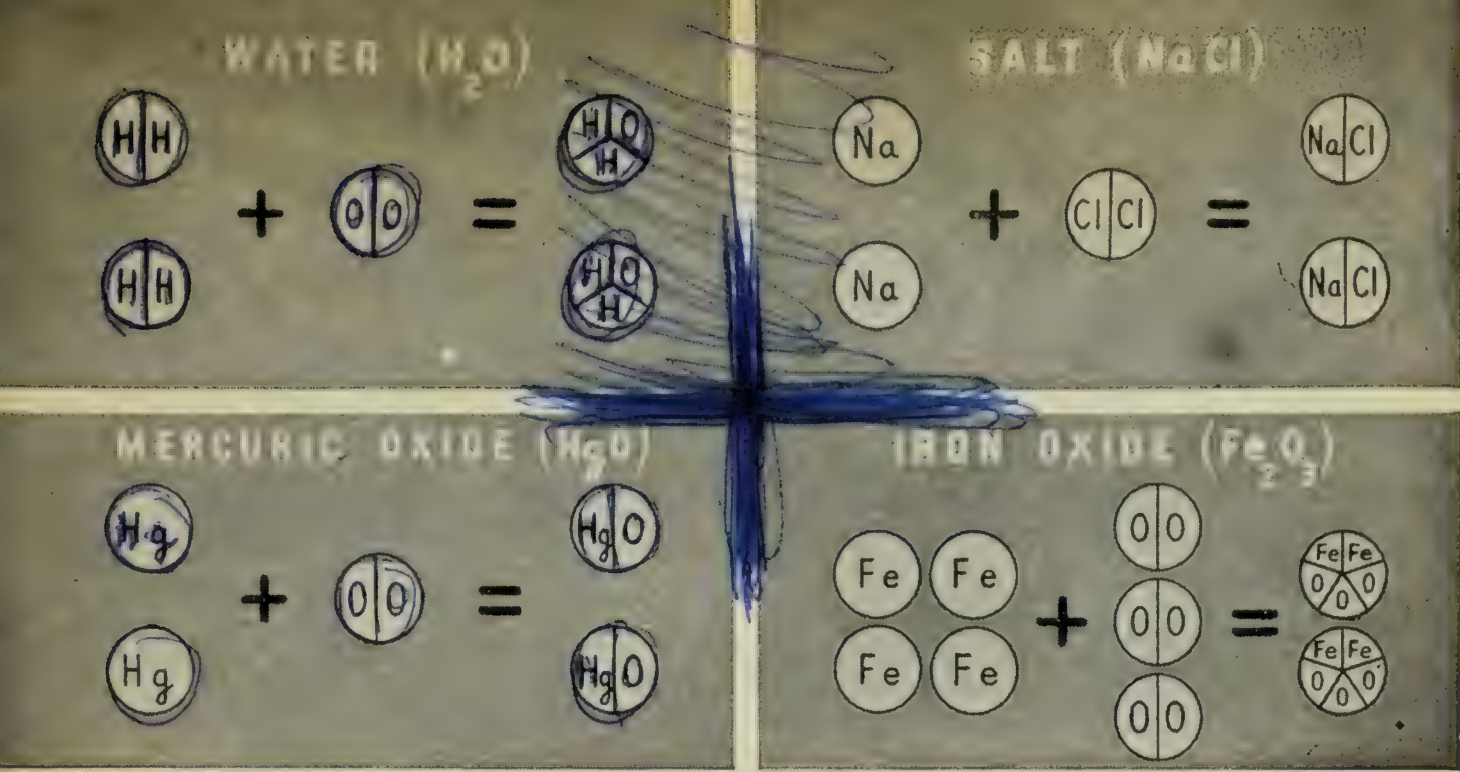


FIG. 48. Each circle represents a molecule of an element or a compound with the atoms in each. Of course, atoms in molecules do not look like this, but the diagrams may help you to see that molecules may contain different atoms. Thus, when 2 molecules (4 atoms) of hydrogen unite with 1 molecule (2 atoms) of oxygen, they form 2 molecules of water, each molecule having 2 hydrogen and 1 oxygen atoms. Explain what the other diagrams show.

$H_2O$

in the molecules. Two molecules of different substances may combine and form one molecule of a compound. This is what happens when iron combines with sulphur. One molecule of iron unites with one molecule of sulphur to make a molecule of iron sulphide. Or a molecule may be decomposed into other molecules. This happens when water is decomposed into hydrogen and oxygen. Two molecules of water decompose into two molecules of hydrogen and one molecule of oxygen.

An interesting kind of chemical change may be seen if a clean iron nail is dipped for a minute into a solution of copper sulphate ($CuSO_4$). When the nail is removed, it will have a coating of copper. This shows that some of the copper atoms must have been taken away from the copper sulphate. By careful tests we find that there is iron sulphate in the solution. Some of the iron atoms from the nail took the place of some of the copper atoms in the solution of copper sulphate. Thus, copper atoms were added to the iron and iron atoms to the copper sulphate.

There are many kinds of chemical changes. All of them are alike in one way: Some change always takes place in the *composition* of the substance, that is, some change in the kinds of atoms in the molecules of the substance.

*Self-Testing Exercises.* Which of the following statements are true concerning molecules? Write the numbers 1 to 10 in a column. Mark the numbers of the true statements wits a plus sign (+) and the numbers of the false statements with a minus sign (—). Use a question mark (?) if you do not know.

1. Molecules cannot be divided into anything smaller and still remain as the same substance.
2. Molecules may contain only one atom.
3. When a molecule of water is decomposed, it breaks up into its atoms.
4. Molecules may be made of many different kinds of atoms.
5. The small figure 2 after H in the formula for water shows that there are two atoms of hydrogen in a molecule of water.
6. A molecule of a compound always has two or more atoms.
7. A molecule of a compound always has two or more different kinds of atoms.
8. When two elements combine to form a compound, the atoms of the elements combine to form new molecules.
9. When a chemical change takes place, there is always a change in the composition of the molecules.
10. There is one atom of sulphate in each molecule of the compound, copper sulphate. (See page 93.)

## Looking Back at Unit 3

1. In this unit you have learned some more science principles that you can use to explain problems. Make a list of them, writing them as sentences.
2. Explain or define each of the following important science words used in this unit:

| | | |
|---|---|---|
| *chemical change* | *melting point* | *evaporation* |
| *boiling point* | *expand* | *Fahrenheit* |
| *centigrade* | *pure substance* | *mixture* |
| *science principle* | *condense* | *combination* |
| *change of state* | *element* | *decomposition* |
| *atom* | *contract* | *freezing point* |

## Additional Exercises

1. In the steel framework of skyscrapers and bridges the steel beams must be riveted together. Why are the rivets heated red-hot before they are inserted and hammered down?

FIG. 49. These two scenes in a large bakery show you how loaves of bread look before and after baking. The dough is full of gas made by the yeast in it. What makes the loaves become large and light after they are placed in a hot oven?

2. Sometimes in the early morning there is a fog. (A fog is made of millions of tiny drops of water floating in the air.) Soon the sun comes out, and in a little while all of the fog disappears. What might be the explanation for this?

3. Find out from the operator of a filling station whether his pump allows for expansion of gasoline in hot weather.

4. Gardeners say that it is better to water lawns and gardens after the sun has gone down than while it is shining. Explain.

5. If you have a medical thermometer at home, examine it and see how it differs from ordinary thermometers in its construction and and in the way it works.

6. Many stoves are equipped with metal thermometers. Find out how they work. What principle of science explains how they work?

7. You can make the most important part of a metal thermometer or of a *thermostat*. Get a thin strip of brass about one quarter inch wide and eight inches long. Obtain a similar piece of iron or steel. Fasten them together with rivets one inch apart. Heat them in the flame of a Bunsen burner. What happens? How do you explain it?

8. Mix a teaspoonful of quicklime with water. Does a chemical change take place? Explain your answer.

9. Make a wall chart of temperatures. Get a piece of wrapping paper 8 or 10 feet long, and make a long bar on it. Start the lower end of the scale at —273° C. Make a mark every 10° up to 1000° C. Place the centigrade reading above the bar. Below the bar place the Fahrenheit reading. Place interesting temperatures at the proper

points along the scale, for example, boiling point of water, freezing point of water, melting point of iron or gold, temperature of the oxyhydrogen blowpipe, temperature of the human body, etc.

10. Heat some sugar in a test-tube. What makes you think a chemical change is taking place? Does the experiment show you anything that might tell you whether sugar is an element or a compound?

11. How does a dissolved solid change the boiling point of water? Find out how hot water gets while it is boiling by holding a chemical thermometer in boiling water. Then add two or three tablespoonfuls of salt or sugar. How does the temperature change?

12. Plan and try an experiment to see if a solution of salt or sugar freezes at the same temperature as water.

13. Why do doctors often keep medicines in ice-boxes?

14. Copper statues become coated with a greenish-black scale when they are out-of-doors. What causes this scale to form?

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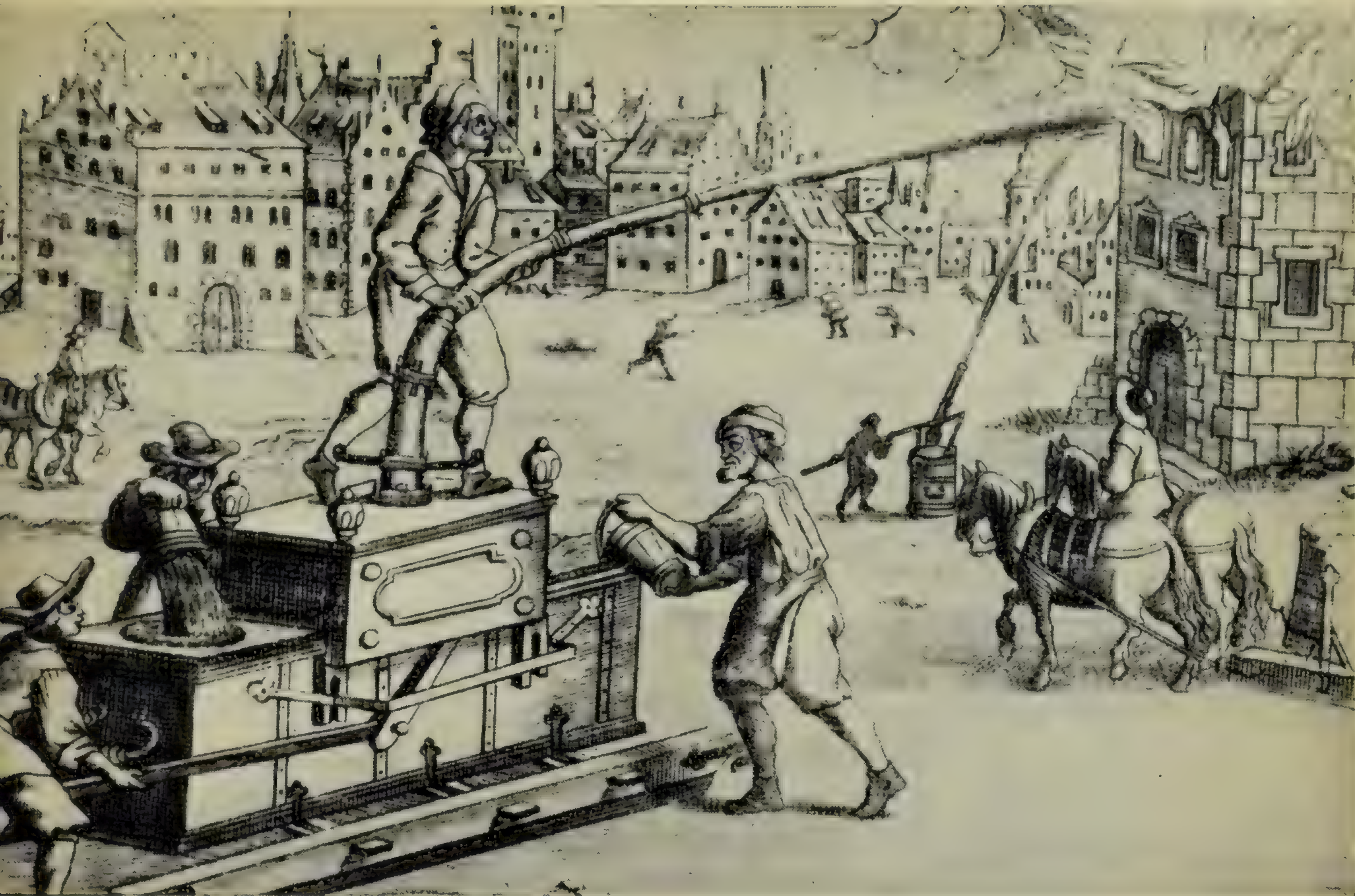

In early times a fire was an even more terrible thing than it is today. There were no efficient fire departments to reach the fire quickly. Messengers ran through the streets, shouting, "Fire," or an alarm bell was rung. The volunteer fire-fighters came out helter-skelter and lost time in trying to locate the fire. Fire pumps have been known since Roman days. The hand fire pump above was used in Venice in 1608. Here you see men filling the water tanks and others working the pump that forces the water out. (Bettmann photo)

# UNIT 4

# How Do We Use and Control Fire?

## Looking Ahead to Unit 4

MANY SAVAGE TRIBES, and some well-civilized races, have worshipped fire. And it is no wonder that people have often worshipped fire. Fire did more for them than almost anything else. With its light they could see at night and could scare away the wild beasts that threatened them. With its heat they could keep warm, cook their food, make weapons and tools, and change clay into brick and pottery. Fire burned their rubbish and helped clear the forests from the land that they needed for their villages and fields. But even civilized people may well regard fire with respect. The ability to use fire is one of the things that makes man different from the animals. Most of the things we have today would be impossible if we did not understand fire and know how to use it.

Surely sometime in your life you have built a fire. Perhaps you built it in the woods or in a stove or a furnace. Probably you started the fire by lighting paper, leaves, small sticks, or shavings. If someone should ask you, "Why did you use these materials to start your fire?" you would probably answer, "They catch fire easily." This is a correct answer so far as it goes. But why do paper and small sticks of wood catch fire more easily than large pieces of wood? If you are building a coal fire, you know that you need to get a good wood fire burning before the coal will catch fire. Why?

We are so accustomed to fire that we are likely not to think about the many things that we cannot explain about fire. To control fire intelligently we need to know the conditions necessary to start a fire, to keep it burning, and to put it out if necessary. We need to understand what burning is. Why do burning mate-

FIG. 50. Almost everyone likes to watch a fire, whether it be in a friendly fireplace, a camp-fire in the woods, or a great building "going up in smoke." There is some mysterious charm in the wavering flames, the glowing embers, and the rising smoke. (U. S. Forest Service photo)

rials give off heat and light? What is a flame? What becomes of a material when it burns? What makes a material a good fuel for us to use? Why will water put out a fire? These are some of the things that you will discover as you study this unit.

## 1. What happens when things burn?

WHAT IS "BURNING"? You might think that the way to find out what happens when things burn is to watch them burn. To be sure, you can learn much that way, especially if you have never watched a fire closely. However, the wisest men watched fire for hundreds of years without finding out what really was going on. When scientists planned some careful experiments to test their ideas, they found out what really happens when materials burn. We shall do two experiments to get some facts about burning. Then we shall see how we can explain these facts.

*Experiment 18 (Pupil or teacher demonstration).* WHAT HAPPENS TO MAGNESIUM WHEN IT IS BURNED? (*a*) Hold one end of a strip of magnesium ribbon in a pair of pliers. Have the other end pointing downward. Heat the lower end red-hot with a match or burner. Observe as well as you can what happens. (The light of the burning magnesium is very bright. You may not want to look directly at it.) Compare the appearance of burned magnesium with unburned magnesium ribbon.

FIG. 51. Apparatus for Experiment 18*b*

*b*) Get the lid from a small tin can. With a hammer and a nail make three holes in the edge of the lid, so that you can hang it up by three wires, as shown in Figure 51. Place the lid with its wires on one side of a balance. Put a level teaspoonful of magnesium powder (or two to three grams of broken magnesium ribbon) in the lid. Add weight to the other side of the balance until the two sides are exactly even. (Dry sand makes a convenient weight.) Hang the lid on a suitable support and heat the bottom with a flame until the magnesium begins to burn. Keep the can lid hot for at least five minutes so that all the magnesium will burn.

As the material cools, notice the color and general appearance of the burned magnesium. Be careful not to lose any of the material. Do you think that burning left the magnesium heavier, or lighter, or the same weight? When the lid is cool, put it back on the balance. Did burning change the weight of the magnesium? How do you know? How do you explain what happened? If you cannot explain what happened, keep the question in mind until you have done the next experiment.

*Experiment 19.* WHAT HAPPENS TO THE AIR IN WHICH IRON RUSTS? (*a*) Wet the inside of a test-tube. Pour a spoonful of iron filings into the tube and shake it until the filings are sticking all over the inside of the tube. Turn the test-tube upside down in a glass of water. Place another test-tube containing no iron filings upside down in a glass of water (Figure 52).

How far does the water rise inside each test-tube? Why does it not rise farther? If something is taken out of the air when iron rusts, what will happen in one of the test-tubes? Why do we also use a test-tube without iron filings? Let the glasses and test-tubes stand for twenty-four hours.

*b*) After twenty-four hours examine both test-tubes. What has happened in each tube? How do you explain what you see? With cardboard, a cork, or your finger carefully cover the mouth of the test-tube containing the iron filings. Lift the test-tube out of the water and turn it over so that you keep the water in the test-tube. Light a splinter of wood. Remove the cover of the test-tube and quickly lower the splinter into the tube and hold it in the air above the water. What happens? Do the same with the tube containing no iron filings. What happens? How do you explain the difference in results? Is the color of the iron filings the same as it was at the beginning of the experiment? Explain, if you can, what happened in the test-tube.

Your experiments have given you at least four very important facts: (1) When magnesium burns, its characteristics change. It is not the same material it was before. You know that this means a chemical change has taken place. (2) When magnesium burns, it gets heavier. (3) When iron rusts in air, some of the air disappears. (4) The part of the air that disappears when iron rusts is the part that is needed for burning. (The splinter would not burn in the tube with rusty iron filings in it.)

Now let us see how we can explain these four facts. Some invisible substance from the air must have joined with the magnesium while it was burning. That was what made the magnesium heavier. The rusting of the iron filings must have taken something out of the air. That was what made the amount of air become less. If you had weighed the iron filings both before and after they rusted, you would have found that the rusted filings were heavier. Like the magnesium, the filings joined with something from the air.

FIG. 52. Experiment 19a

You probably know that the substance used from the air is called oxygen. It is one of the chemical elements that make up all the materials in the world. Careful experiments, somewhat like the one with the iron filings, show that about twenty-one per cent of the air is oxygen.

When oxygen from the air united with the magnesium, a new substance was formed. This new substance was a compound because it contained elements that had been united chemically. Compounds that contain oxygen and one other element are called *oxides*. The white compound of magnesium (Mg) and oxygen (O) that you made in Experiment 18 is magnesium oxide (MgO). You can now write a sentence that tells what happens when magnesium burns.

MAGNESIUM (*a silvery metal*) and OXYGEN (*a colorless gas*) unite and form MAGNESIUM OXIDE (*a white powder*).

You can also write a sentence about the rusting of iron.

IRON (*a silvery metal*) and OXYGEN (*a colorless gas*) unite and form IRON OXIDE (*iron rust*).

The burning of magnesium and the rusting of iron are chemical changes. The materials combined, or united, with oxygen to make new substances. This kind of chemical change is called *oxidation*, and when it takes place, we say that a material *oxidizes*. The magnesium oxidized when it burned, and the iron oxidized when it rusted. They both joined with oxygen from the air to make new substances.

*Self-Testing Exercises.* 1. Why does magnesium get heavier when it burns?

2. Do you believe that iron takes oxygen from the air when it rusts? Why?

3. How much of the air is oxygen?

4. What is meant by an oxide? Give an example of one.

WHY DOES BURNING MAKE THINGS HOT? When the magnesium burned in Experiment 18, you found that it gave off both light and heat. This also happens when wood, coal, or gasoline burns. Where does this heat come from? Of course, to

FIG. 53. Antoine Lavoisier, a French chemist who lived about 150 years ago, was the first person actually to prove that oxygen in the air is the cause of all burning. In his experiments he found that mercury united with a certain amount of oxygen to form a red powder. When the red powder was heated, it gave up that same amount of oxygen. Read pages 49-50 again. (Bettmann photo)

start these fuels burning we light a match and bring it to the fuel. The match itself gives off light and heat, but the amount of heat it gives off is very small compared with the heat and light given off by the fuel when it gets to burning. So the heat must somehow or other come from the material that is burning.

Before you can understand how heat is produced in burning, you must understand the meaning of the word *energy*. Perhaps you think you know what it means. You have heard people say, "I have a lot of energy." When they say this, they mean that they feel so well and strong that they can work or play hard. Scientists use this term in a little different way. They think of energy as something that makes matter do things or makes matter change.

Now let us think about heat. Is heat energy? You know that heat makes substances expand, and it makes them change from a liquid to a gas. Heat also makes chemical changes take place faster. According to our definition, therefore, heat is energy because heat makes matter do things. Light, too, is a kind of energy. When light falls on the film of a camera, it changes the chemicals on the film so that a picture may be produced. Light makes cloth and paper fade because it changes the chemicals in them. Because light can do these things to matter, it, too, is a

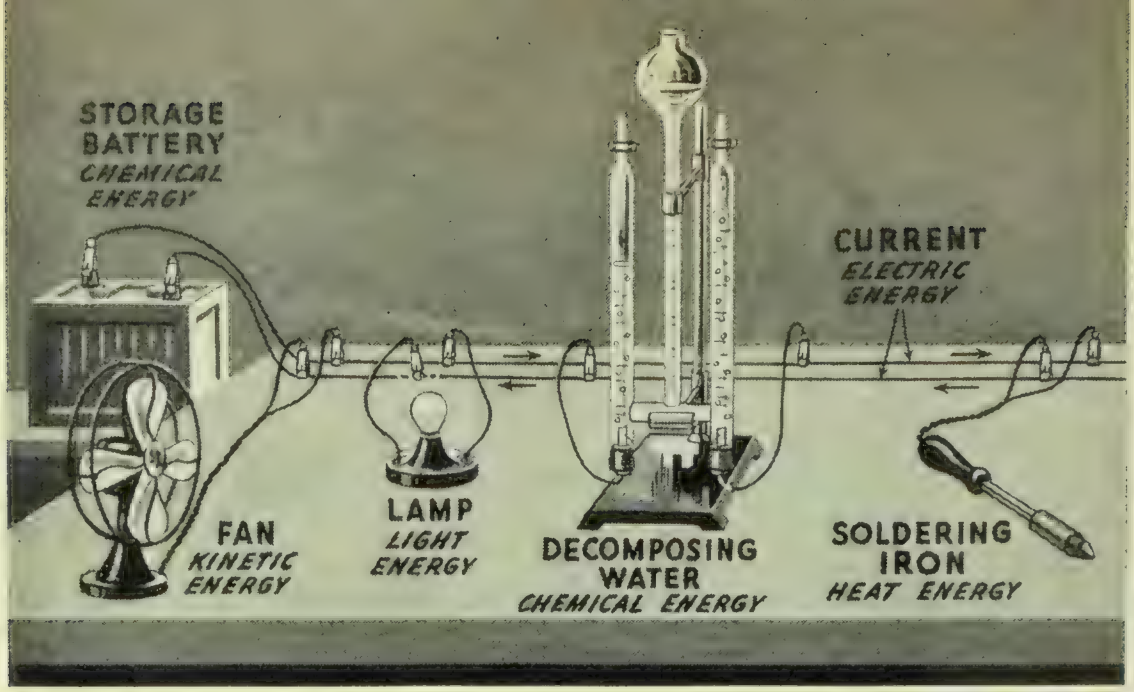


FIG. 54. Notice all the different forms of energy that come from the chemical energy of the battery. Electric energy comes first. This form of energy is changed into the mechanical energy of the moving fan, the light energy of the bulb, the heat energy of the soldering iron, and back again into chemical energy when it decomposes water into the elements of which it is made, namely, hydrogen and oxygen.

kind of energy. You can easily see that electricity is a kind of energy. When an electric current is sent into an electric motor, a wheel inside the motor is forced to whirl at a high rate of speed. The wheel of the motor has energy, too, because it can drive an electric fan, a sewing-machine, or a saw. From these illustrations you see that energy can do things. It can make things move, and it can cause changes to take place in matter.

In all these examples you probably noticed that when a certain kind of energy appeared, it was changed from another kind of energy. Let us consider another example to make this clear. Water at the top of a dam has energy. This energy is stored energy which can be released if the water is allowed to fall over the dam on to a water-wheel. The moving water-wheel has what we call *mechanical energy*. The mechanical energy of the water-wheel is changed to electrical energy in a dynamo when the water-wheel is used to run the dynamo. The electrical energy from the dynamo is sent into wires and is changed to heat and light energy by electric light-bulbs. Wherever energy appears, you may be sure that it comes from some other kind of energy.

Now that you know what energy is, let us return to our burning fuel. How is heat produced? You know that the heat energy must come from some other kind of energy. All materials con-

tain a kind of energy called *chemical energy*. Under certain conditions this chemical energy can be changed to heat energy. This happens when a material unites with oxygen. Some of the chemical energy of the material is changed into heat energy. This makes the burning material, as well as materials around it, hot.

Now let us return to Experiments 18 and 19. In these experiments you saw that the burning of magnesium and the rusting of iron are both examples of oxidation. Why, then, are there heat and light when magnesium oxidizes but not when iron oxidizes? Let us first see about heat. When oxygen combines with a substance, heat is always produced. But some substances combine so slowly with oxygen that you cannot feel the heat. The part of the iron that is rusting gets warm when the iron combines with oxygen. But the iron and the oxygen are uniting so very slowly that the iron never gets hot enough for you to feel any change in temperature. Magnesium combines so rapidly with oxygen that great heat is produced in a short time.

Why do we sometimes get light when materials oxidize? And why is there sometimes no light when a material joins with oxygen? You have probably guessed the answer. There is no light unless there is a great deal of heat. Iron joins so slowly with oxygen that there is not enough heat to make the iron glow. But touch a match to paper, and the paper unites so rapidly with the oxygen in the air that it bursts into a fire that gives off both heat and light. Materials must be very hot to give off light. They do not get hot enough when they join slowly with oxygen.

When oxidation takes place so rapidly that we can both feel heat and see light, we say that the material *burns*. When wood, paper, coal, gasoline, or gas combines with oxygen, heat and light are produced. We say that these materials burn. But, as you can see, burning and rusting are the same kind of chemical change. Oxygen unites with a substance in both cases and produces oxides. Of course you know that many materials will not burn. Some of them will not combine with oxygen at all. Water, for example, will not unite with oxygen. Some materials will unite with oxygen but not fast enough to make light. When a material will burn, we say that it is a *combustible material*. A material, such as glass, that will not burn, is said to be *incombustible*.

FIG. 55. Exp. 20*a* FIG. 56. Apparatus for Experiment 20*b*

*Self-Testing Exercises.* 1. Write a paragraph of not more than one-half page in which you answer the question, "What is energy?"

2. When a certain kind of energy appears, where does it always come from?

3. Name one way in which the chemical energy stored in materials may be changed to heat energy.

4. In what way are the burning of iron and magnesium alike? In what way are they different?

5. What is the difference between "burning" as we usually use the term and "oxidation"?

*Problems to Solve.* 1. State three examples of your own to show the change of one kind of energy to another kind.

2. What reason could you give to explain why painting iron keeps it from rusting?

HOW DO OUR COMMON FUELS BURN? You found that magnesium was heavier after it was burned because oxygen had been joined to it. But when you burn wood or coal, the *ashes* that are left do not weigh as much as the wood or coal that you burned. And oil disappears entirely when we burn it. There seems to be a contradiction here. Where do these materials go when they burn? To find the answer to this question, we will study a burning candle. The wax of a candle is made of paraffin. Paraffin is a compound made of two elements, carbon and hydrogen. From what you have learned about burning, what compounds do you believe will be formed when the candle burns?

*Experiment 20.* WHAT HAPPENS WHEN A CANDLE BURNS? (*a*) Light the very tip of a candle wick. Watch to see what happens as the flame grows larger. What happens to the wax around the wick? Is the centre of the candle flame light or dark? Hold a match stick horizontally across the flame just above the wick until it starts to burn (Figure 55). Remove it quickly from the flame and extinguish it. Examine the stick. Does the burning take place inside the candle flame or on the outside of the flame?

FIG. 57. Experiment 20*d*

Blow out the candle and then quickly bring a lighted match to a point about one-half inch above the wick. What happens? Is the paraffin a solid, a liquid, or a gas when it burns? How do you know?

*b*) Light a candle. When the flame has grown to full size, hold a white dish in the yellow part of the flame. What collects on the dish? It is carbon. Where did it come from?

*c*) Light a candle. Hold a cool, clean beaker, tumbler, or wide-mouthed bottle, mouth downward, over the flame for a short time. Do not let the flame touch the glass. What appears on the glass? Does it disappear when you hold the beaker away from the candle for a little while? Breathe into the beaker. Does your breath make a similar film? The film that the candle flame makes on the glass is composed of very tiny droplets of water ($H_2O$). Where do you think this water came from?

*d*) Fasten a wire around a short piece of candle. Bend the wire to make the candle hang straight. Lower the lighted candle into a jar and cover the jar with a piece of glass. Remove the candle and quickly replace the cover. Pour in a little limewater and shake it up with the air in the bottle. Did the limewater turn milky? Carbon dioxide always makes limewater turn milky; limewater is a chemical test for carbon dioxide. Did the candle give off carbon dioxide?

Now let us explain what happens in the burning candle (Figure 58). Heat from the burning match melts the paraffin wax in the wick. Some of the wax changes to a gas because it is heated, and the gas, because it is hot, unites with oxygen and burns. The heat from the burning gas melts the wax at the top of the

candle. The melted paraffin travels up the wick in just the way that ink soaks through blotting paper. When it reaches the flame, the heat changes it to a gas. The paraffin compound becomes so hot that it breaks up into carbon and hydrogen.

The carbon particles in the flame are so hot that they glow and give off a yellow light. When the particles reach the oxygen on the outside of the flame, they combine with oxygen and form carbon dioxide. The hydrogen combines with oxygen to form hydrogen oxide, or water. Since the temperature is very high, the water is in the form of water vapor. Both the carbon dioxide and the water vapor are colorless gases, and they mix with the air. Thus the candle gradually disappears. You can now write three sentences that will tell what happens when a candle burns.

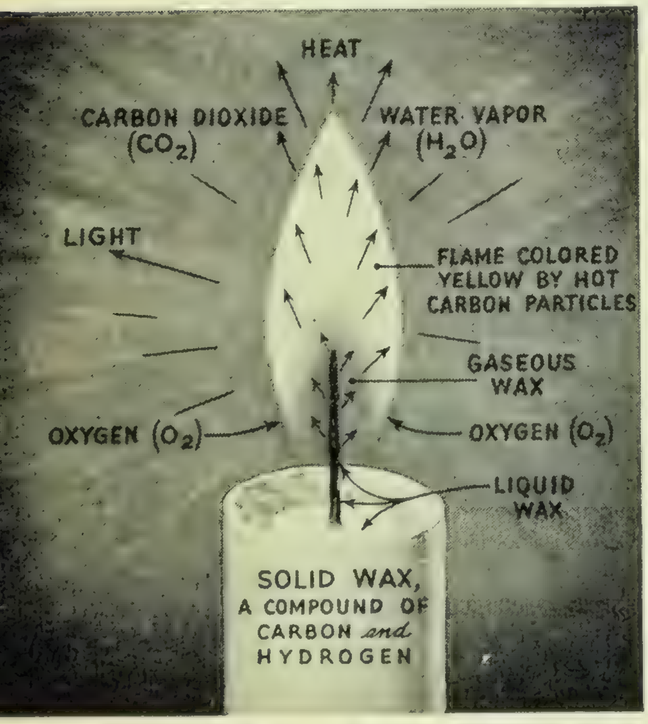


FIG. 58. A diagram of a burning candle

PARAFFIN WAX (*a solid white compound*) is separated into its elements, CARBON AND HYDROGEN.

CARBON (*a black solid*) and OXYGEN (*an invisible gas*) unite and form CARBON DIOXIDE (*an invisible gas*).

HYDROGEN (*an invisible gas*) and OXYGEN (*an invisible gas*) unite and form WATER VAPOR (*an invisible gas*).

If you understand what happens when a candle burns, you can understand what happens when any fuel burns. All of our fuels (oil, wood, coal, gas, etc.) contain compounds of carbon and hydrogen. Some also contain carbon and minerals that are mixed with these compounds. When fuels burn, the carbon and hydrogen form carbon dioxide and water vapor; these mix with the air and disappear. The minerals do not combine with oxygen and are left as ashes.

You have just learned what happens when fuel is completely burned. But fuels are not always completely burned. Often there is not enough oxygen to make all of the carbon burn. Sometimes

the carbon is not heated enough to combine with oxygen. When these things happen, we see the unburned carbon as black smoke. Usually smoke is produced when too much fuel is added. Some of the whitish or bluish smoke from fires is powdered ashes and other substances that do not change to invisible gases as the fuel burns. Smoking fires have two great disadvantages. First, the carbon that does not burn is wasted. Every ton of *soot*, or unburned carbon, that goes up the chimney is a ton of fuel lost. The chemical energy in it is not changed to heat energy. Second, the soot itself is a nuisance. It darkens the sky, shuts out the healthful rays of the sun, and makes dirty places in which to live.

Sometimes when fuels burn where oxygen is not plentiful, carbon monoxide ($CO$) is formed, instead of carbon dioxide ($CO_2$). Carbon monoxide is a very poisonous gas. Some of it is formed when gasoline burns in an automobile motor. The gas then comes out the exhaust pipe. That is why you must never stay in a closed garage while an automobile engine is running.

*Self-Testing Exercises.* 1. Explain why fuels give off heat and light when they burn.

2. What two gases are formed in large amounts when fuels burn? Explain. How can you show that these gases are formed?

3. Why do fuels almost disappear as they burn? What substances in fuels do not burn?

*Problems to Solve.* 1. Coke burns, but it sometimes burns without a flame. Why does it burn differently from coal?

2. A tea-kettle full of cold water will often become coated on the bottom with a film of water when placed over a lighted gas-burner. Explain where the water comes from.

3. Does the wire inside an electric-light bulb really burn? (The bulbs are filled with a gas called argon.) Explain your answer.

4. Can you get the gas out of the inside of a candle flame? Use a piece of glass tubing about four or five inches long, with a medium-sized opening ($\frac{3}{16}$ to $\frac{1}{4}$ inch). Wrap both ends of a wire around the tube to make a handle. Then hold it in a sloping position with the lower end just above the tip of the wick in a large candle flame. When a white cloud begins to come out the upper end of your tube, see if you can light it with a match or other flame.

5. Why does not the water formed in the flame of a burning fuel put out the fire?

FIG. 59. Many savage tribes know how to start fire by rubbing two things together. This can be done in several ways. A common way is to whirl a stick in the notch of a board until the wood powder that is made begins to glow. Some Boy Scouts can make fire by this plan in less than a minute. (Boy Scouts of America photo)

## ¶ 2. How do we make fire?

HOW DO WE MAKE THINGS HOT ENOUGH TO BURN? When you want to start a fire, you must do three things: (1) You must get some material that will burn—some combustible material. (2) You must see that a supply of oxygen reaches the combustible material. (3) You must heat the combustible material until it gets so hot that it begins to burn; that is, you must heat it to its *kindling temperature*. Whenever these three essentials are provided, a fire starts. Whenever one of them is lacking, the fire will not burn.

Let us see first how materials catch on fire. When you hold a lighted match to a piece of paper, the heat from the match raises the temperature of the paper to the point where it will combine rapidly with oxygen. The paper bursts into flame. We use paper to start a fire because it is thin. Only a little heat is needed to raise it to its kindling temperature. The heat from the burning paper raises the temperature of the small sticks to their kindling point. These, in turn, heat the coal, or large pieces of wood, to the kindling point. You can see now why we start a fire in the way we do. We use materials with low kindling temperatures to heat materials with higher kindling temperatures.

In pioneer days the great problem in starting a fire was to get things hot enough to burn. You have read how the pioneers were always careful to have flint and steel and *tinder* in the tinder-box. Tinder was something that took fire very easily. To make it, they heated cotton or linen cloth in the oven until it was brown and ready to burn, or they shredded and dried the bark of certain trees. Then they put this tinder in a tin box to keep it perfectly dry. To make a fire they placed some tinder on the ground. Then they struck the piece of flint rock against the steel. The sparks that flew off set the tinder on fire. If a pioneer could not make fire with his flint and steel, he might have to carry an iron kettle for miles to "borrow fire" from a neighbor.

When chemists learned that they could get heat by mixing chemicals and starting a chemical change in them, they tried to find a quick, easy, and safe way of kindling fires. Many plans were tried before our modern matches were invented. The first matches were made in 1827.

The heads of matches have, at the very tip, a chemical called phosphorus sulphide. This chemical begins to burn at a rather low temperature; therefore it is easy to get enough heat to start it burning. The rest of the match head contains (1) a chemical that gives off oxygen when it is heated, (2) ground glass to increase friction, and (3) glue to hold the chemicals on the stick. When the tip is rubbed quickly over some rough surface, the friction makes the phosphorus sulphide hot enough to burn, and, with the help of the other chemicals, the stick is set on fire. Ordinary "strike-anywhere" matches are often set on fire accidentally. To prevent accidental fires safety-matches have part of the chemicals on the box or cover and part on the match. Thus a safety-match will seldom take fire unless rubbed on the box.

Electricity can be used to make things hot enough to burn. Electric current sent through certain kinds of wires heats them red-hot. Some cigar-lighters in automobiles work on this plan. Accidental fires are started rather often from the hot wires in electric irons and toasters. Electric sparks easily set fire to combustible gases.

Sometimes combustible materials make themselves hot enough to burn. When this happens, we call it *spontaneous combustion*,

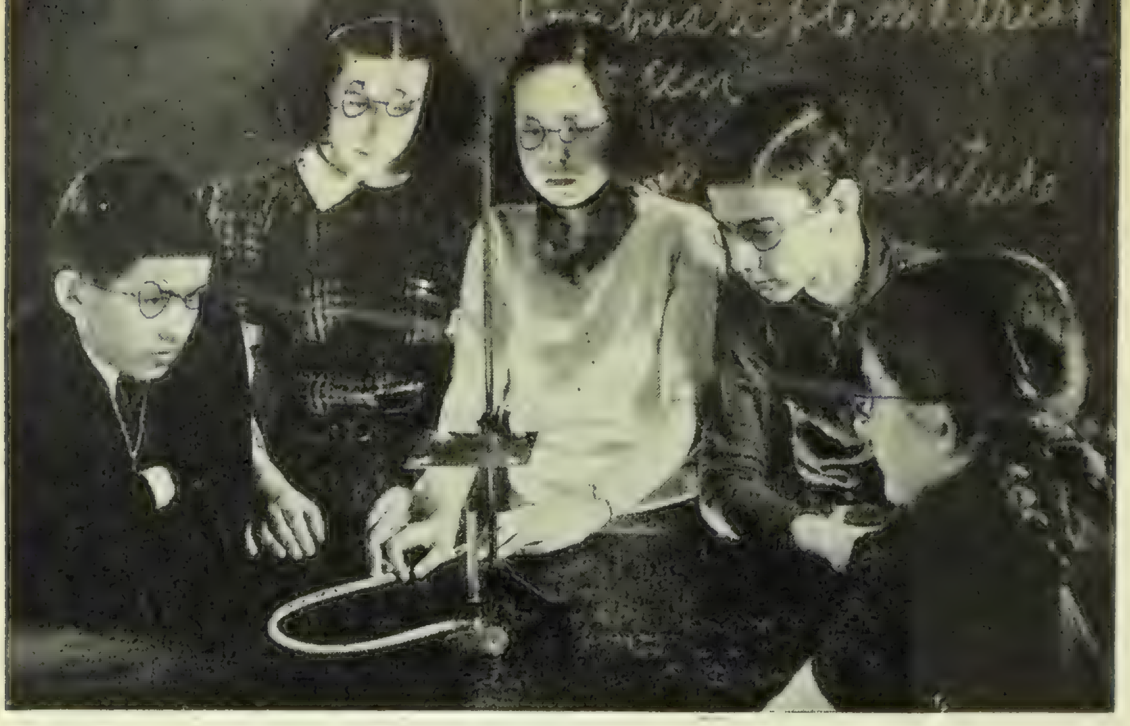

Fig. 60. Apparatus for Problem to Solve 1

or self-kindling. How can this happen? One of the most common kinds of spontaneous combustion takes place in rags that have been used to wipe up linseed (flaxseed) oil or paint made from linseed oil. The oil unites slowly with oxygen from the air. This chemical change gives out heat. When the oil is spread out on the side of a house, the heat passes off into the air. But when the oil is inside a pile of rags, the heat is held in. The inside of the pile gets warm. The heat cannot escape; so the rags get warmer and warmer until they reach their kindling temperature. Then they burst into flame.

*Self-Testing Exercises.* 1. What three things are necessary in order to make a fire?

2. What are three different ways of making things hot enough to burn?

3. Why is it necessary to "strike" a match?

4. What is spontaneous combustion? How does spontaneous combustion start a fire?

5. Why will some matches strike anywhere, while others must be rubbed on the match box?

*Problems to Solve.* 1. Test the kindling temperatures of sulphur, a match head, a piece of wood, and a piece of paper, as shown in Figure 60. Which has the lowest kindling temperature?

2. How can a magnifying-glass be used to start a fire? Try to get a magnifying-glass and start a fire with it.

3. Borrow a friction cigar-lighter and see how it works.

4. Why does dry wood "catch fire" more easily than wet wood?

HOW DO FIRES GET OXYGEN? The second essential of fires is a supply of oxygen. As you know already, about one-fifth of the air is oxygen. This oxygen in the air supplies the oxygen for most fires. But what happens when all the oxygen in one part of the air has been used up? When a candle is put under a jar or inside a stoppered bottle, it soon goes out because it runs out of oxygen. Out in a room a candle never runs out of oxygen. Why does it not use all the oxygen around it and then go out?

Someone has said, "A fire provides its own supply of fresh air." You can easily see how this happens.

*Experiment 21.* HOW DOES A FIRE GET ITS SUPPLY OF FRESH AIR? Light a candle or a kerosene lamp. Hold a piece of smoldering punk above the flame and then below the flame. (If you have no punk, you may make *touch paper* by soaking filter paper or blotting-paper in a solution of potassium nitrate and then letting it dry. When it is lighted, it will smoke.) The smoke will show the direction of the air currents. Which way is the air above the flame moving? Which way is the air below and at the side of the flame moving? How does this movement help the fire get fresh air?

The experiment shows that there is a current of air upward above the fire. The used gases from the flame thus go away, and fresh air containing oxygen moves in toward the flame, as shown in Figure 61. In this way there is a constant circulation of air. In a later unit you will learn how this current of air is caused. We often speed up the air currents so that fires will get more oxygen and burn more brightly. An experiment will make clear to you how this is done.

FIG. 61. The arrows show the movement of the air currents around a burning candle.

*Experiment 22.* WHY DOES A CHIMNEY HELP A FIRE BURN BETTER? Light a kerosene lamp, but do not put the glass chimney on. Notice how bright the flame is. Use the smoke from a burning punk stick or from a narrow strip of touch paper to see where the air currents are going into the burner.

Now turn up the wick of the lamp until it begins to smoke. It smokes because there is not enough oxygen going into the flame to burn all the carbon from the oil. Put on the chimney. What effect does the chimney have on the brightness of the flame? Does the flame stop smoking? Why? Test the air currents again so that you will be sure you know how they act.

The chimney of a kerosene lamp makes the lamp burn better because it separates the warm air above the flame from the cool air outside the chimney. Thus the air current can move more rapidly, and the flame gets a better supply of oxygen. More oxygen makes the flame brighter because all the carbon can burn. Our stoves and furnaces are also provided with chimneys to give the fires a better supply of oxygen. If you have ever tended such a fire, you know how the air rushes into the stove or furnace through the open doors. This movement of air up through a fire is called the *draft*. Chimneys also help us by carrying the smoke and sparks from fires high up into the air, so that they are extinguished before they fall back on the roof. In this way they protect us and our buildings from accidental fires.

*Self-Testing Exercises.* 1. How would you build a camp-fire or a bonfire so as to be sure that the three necessary things are provided?

2. How is a supply of oxygen brought to a bonfire?

3. What are two ways in which man helps his fires get a good supply of fresh air?

4. Give two reasons why we have chimneys in our homes.

*Problems to Solve.* 1. When a large fire is burning, a wind is set up in the immediate vicinity. Explain.

2. Why does fanning a smoldering fire make it burst into flame?

HOW DO WE GET OUR IMPORTANT FUELS? The third essential of fire is something that will burn, that is, some combustible material. Of course, many substances that will burn cannot well be used to heat our homes. Combustible materials that are good for fuel must burn rather easily and give off large amounts of heat. We must also be able to get all of them we need without paying too much for them. In 1924 Canada burned nearly 22,000,000,000 cubic feet of natural gas; and every year millions of gallons of petroleum are used in the place of coal.

Under Canadian soil lie 1,234,829,000,000 tons of coal, which at the present rate of mining would supply Canada with fuel for 100,000 years. Yet with so much of her own, Canada buys from other countries 50% of the coal that she consumes. The reason for the anomaly is that nature has stored most of the coal on the one hand in Nova Scotia, and on the other in Alberta and British Columbia. Both of these regions are many miles from the densely populated districts. The whole problem in Canada is largely a question, therefore, of finding means of carrying coal cheaply from the rims of Canada to the industrial centre.

Wood from trees was the first and easiest fuel to get. But in civilized countries much of the forest has been cut for lumber and to clear the land for farms. In large cities wood is usually more expensive than coal and thus is not often used. Other fuels, such as coal and oil, are better than wood because they give out more heat per pound. We can get as much heat out of two pounds of coal as we can get out of three pounds of good wood.

Coal, as you know, is dug from the ground. There are two important kinds of coal: *bituminous*, or soft, coal, and *anthracite*, or hard, coal. Bituminous coal is about fifty-four per cent pure carbon. About forty per cent of the carbon is combined with hydrogen, oxygen, nitrogen, and sulphur. When soft coal is heated in a fire, these compounds of carbon change to gases. Often these gases are not completely burned, and a great deal of smoke is made. Soft coal is cheaper than hard coal and is the kind we usually burn in homes, factories, and locomotives.

Anthracite coal is about ninety-five per cent pure carbon and less than five per cent carbon compounds. When it is heated, only a little gas is given off. Therefore, it burns with less smoke. It also burns more slowly than soft coal; therefore the fire needs less attention. People prefer anthracite coal for homes because it is not so dusty and because it burns more evenly.

Soft coal is important because we get coke and gas from it. You can make some coke and gas yourself.

*Experiment* 23. HOW ARE COKE AND GAS MADE FROM SOFT COAL? Fill a test-tube one-fourth full of crushed soft coal and fit it with a rubber or wet clay stopper and tube as shown in Figure 62. Heat

FIG. 62. Apparatus for Experiment 23

the coal strongly with a burner. As soon as possible, light the gases that are given off by the coal. When no more gas is given off, let the test-tube cool. Then break the tube and examine the coke. (You can do this experiment at home by putting the coal in a coffee can that has a hole punched in the lid. Heat the can on the gas stove, electric stove, or in a coal or wood fire. Be sure to burn the gases that are given off.)

Coke, made by heating coal as you did in Experiment 23, is almost pure carbon. It is rather hard to start burning, but once started, it gives intense heat with practically no smoke. It is often mixed with soft coal in furnaces. The coal burns more easily than coke, and thus keeps the coke burning. The gas that comes from heating soft coal contains many impurities. These impurities are removed before the gas is sent through pipes to our houses.

Oil wells and gas wells are also extremely important as sources of fuel in Canada. Oil from oil wells is called *petroleum* or *crude oil*. Petroleum is a black, bad-smelling liquid which is a mixture of many different compounds of carbon and hydrogen. Each compound has its own boiling and condensing temperature (see pp. 68 and 72). To separate these compounds the crude oil is heated in large *stills* in factories called *oil refineries*. The compound that evaporates easiest soon changes to a vapor. This vapor is led into a pipe where it is cooled and condensed back to a liquid. The oil is then heated to a higher temperature until the next compound changes to a gas and so on. Gasoline comes off first, and then kerosene. The refineries may be near the oil fields or

hundreds of miles away. Some of the oil rides in tank cars on a railroad, but much of it goes through underground pipe lines. From petroleum we also get paraffin, oil for our automobile engines, and oil to burn in furnaces.

Above the petroleum in oil wells, and in some places where no oil is found, drillers strike natural gas. In parts of our country where natural gas is plentiful, it is used as a fuel for heating, lighting, and power. In recent years natural gas has been piped to some of the larger cities.

TABLE 7. VALUE OF NATURAL GAS PRODUCED IN CANADA

| YEAR | NEW BRUNSWICK | ONTARIO | ALBERTA | CANADA |
|---|---|---|---|---|
| 1936 | $298,819 | $6,052,294 | $4,376,720 | $10,762,243 |
| 1937 | 283,922 | 6,588,798 | 4,766,437 | 11,674,802 |
| 1938 | 284,000 | 6,583,875 | 4,948,600 | 11,847,803 |

*Self-Testing Exercises.* 1. Not all combustible materials are used for fuel. Why?

2. Make a table with three columns. In the first column make a list of the natural fuels and below that make a list of the manufactured fuels. In the second column write opposite each fuel one of its advantages, or good characteristics. In the third column give a disadvantage of each fuel.

3. Describe briefly how coal gas is made.

4. Where is natural gas found? What is it used for?

5. How do we get gasoline and kerosene from crude oil? Which of these two is more important? How do you know?

*Problems to Solve.* 1. Early in the morning when people are refuelling their fires, you often see much black smoke coming out of the chimneys. What is the probable cause of this? How can it be prevented?

2. Find out what scientists mean by the *fuel value* of a fuel. Which has the greatest fuel value, wood or hard coal or soft coal?

## ¶ 3. How do we regulate fire?

A FIRE THAT WE CANNOT CONTROL does very little good. It may run wild and destroy many things, or it may burn so slowly that it does not give us the heat that we need. Sometimes we want to keep a fire from getting started or to stop it if it gets

started. In Problem 4 you will study how destructive fires are put out. In this problem you will learn how the fires that we use in our homes and factories are made to burn the way we want them to burn.

In Problem 2 you learned that a fire must have three things: oxygen, some material that will burn, and heat enough to start the burning. If any one of these is lacking, no fire will ever start. If you take away any one of these, a fire will stop burning. If you can regulate the supply of oxygen or the supply of fuel, or both, a fire will burn as rapidly or as slowly as you wish. Let us see how we regulate our many different kinds of fires.

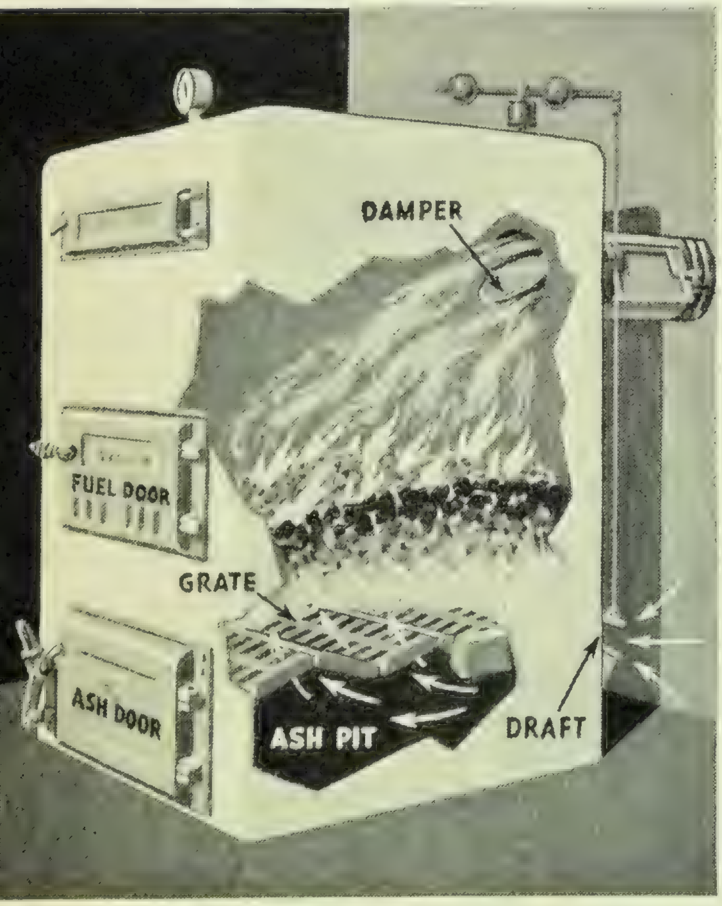


FIG. 63. Part of the furnace is cut away to show the grate that holds the fuel.

HOW DO WE REGULATE THE FIRES IN STOVES AND FURNACES? After man had used open fires for thousands of years, he learned that he could get more of the heat from the fire if the fire were enclosed in some kind of unburnable box. So he made an iron fire box and called it a stove. When he made the fire box large enough to heat a whole building and placed it in the basement, he had a furnace. Fire in stoves or furnaces heats buildings with less fuel than we would need to use in open fires. This is true for two reasons. First, the fire box with its chimneys and pipes helps keep the heat from escaping into the outdoors. Second, furnaces and stoves are so made that we can regulate the supply of oxygen that goes into the fire box to make the fire burn the way we want it to.

Of course, any stove or furnace must have a pipe and a chimney to carry away the gases and smoke. The pipe usually is connected near the top of the furnace. At the bottom of the furnace,

below the *grates* that hold the fuel, we find an opening, called a *draft*. The draft is arranged so that we can open it as much as we wish or close it entirely. In the pipe leading to the chimney we find a circular piece of metal, called a *damper*. This is used to open and close the pipe. When we start a fire, we open the damper in the pipe. We also open the draft. Thus there is a free passage of air coming in at the bottom of the furnace and passing up through the fire and out the pipe to the chimney.

If the draft is strong, it makes the fire burn rapidly. By opening or closing the draft and the damper just the right amount, we can make the fire burn as rapidly or as slowly as we wish. After the fire is well started, we close the draft so that the rush of air will not carry so much heat up the chimney. We can also regulate the oxygen supply by the amount of fuel we put on the fire. Too much fuel chokes a fire because the air cannot pass through the fuel and give it oxygen. Ashes on top of the grate also keep the air from getting to the fire.

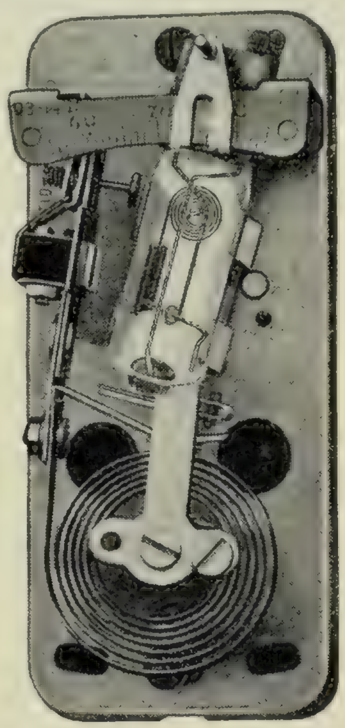

FIG. 64. What science principle explains how the metal coil can turn the electricity on and off?

Many modern furnaces have an electric motor that opens and closes the drafts after the fire is started. In the rooms heated by the furnace is a *thermostat*. This device is a kind of metal thermometer. When the room is warm enough, the thermometer makes two pieces of metal touch. An electric current then runs the electric motor just long enough to close the drafts. Later, when the room gets cool again, the thermometer makes two other pieces of metal touch. This again turns on the current, and the motor opens the drafts. When the thermostat is set right and the fire is properly built, the furnace may need no attention for several hours.

A coal furnace is even more easily regulated when the coal is fed in by a machine called a *stoker*, as shown in Figure 65. One great advantage of electric stokers is that they feed the fresh coal into the bottom of the fire instead of on top. When coal is put

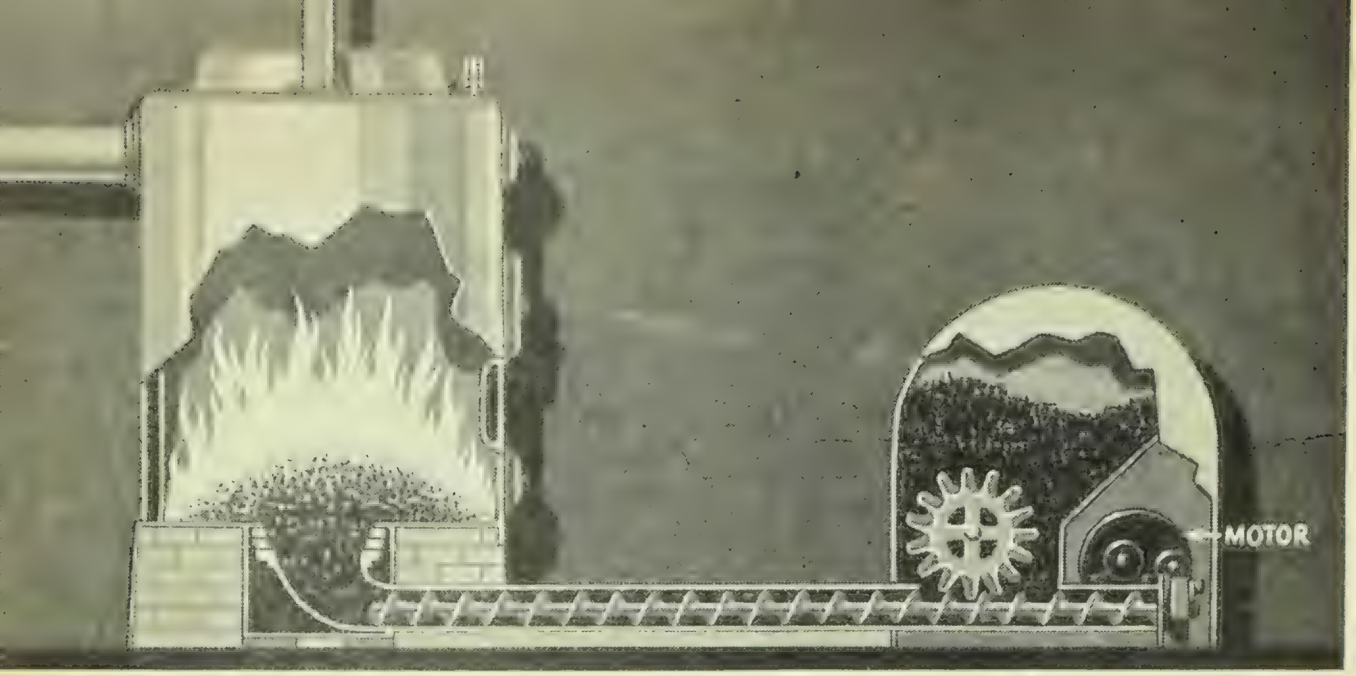


FIG. 65. In an electric stoker the coal is placed in a *hopper*, and a long screw, called a *feed worm*, run by an electric motor, pushes the coal from the hopper through a tube and up into the fire. At the same time a fan blows air into the fire to help it burn better. The motor is turned on and off by a thermostat. The person who takes care of the fire has only to fill the hopper once in awhile and take the ashes out.

on top of a fire, much gas passes off unburned before the coal gets hot enough to make the gases burn. But when the coal is fed in beneath the fire, the gases are heated very hot as they go up through the hot coals. By the time they get up to the place where the coals are burning, they are so hot that they combine easily and quickly with oxygen; therefore, they burn more completely. Since the gases given off by the heated coal are more completely burned, there is hardly any smoke.


FIG. 66. The parts of a kerosene-stove burner

HOW DO WE REGULATE THE FIRE IN KEROSENE AND GASOLINE BURNERS? Most kerosene burners (Figure 66) are made much like kerosene lamps. Oil comes to the bottom of each burner through a pipe. A woven cotton wick in the form of a hollow cylinder dips into the oil and passes up into the burner. The oil enters the wick and soaks through to the top. The wick can be moved up or down so that more or less of it is at the top of the burner. The kerosene, when heated, evaporates from the part of the wick above the burner. Thus by turning the wick up or down, you can regulate the amount of kerosene that will evaporate and burn.

The chimney of a kerosene burner makes a good draft, like any other chimney. Openings on both sides of the wick send strong currents of fresh air into the burner. This large supply of air quickly burns the fuel and makes a hot, blue flame instead of the yellow flame of the kerosene lamp.

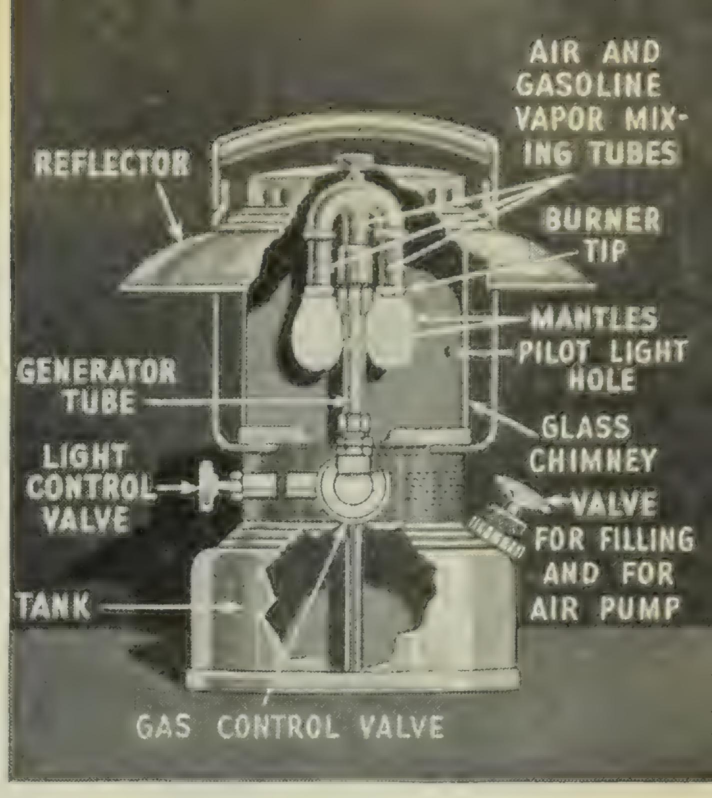


FIG. 67. The parts of a pressure gasoline lantern

Gasoline also is used as a fuel in lamps and stoves. A common type of pressure gasoline lantern for use in homes is shown in Figure 67. The gasoline is in a pressure tank at the bottom. Before the gasoline can be burned, it must be changed from a liquid to a gas, or a vapor. This is done in a *generator tube*. Air is pumped into the tank with an air pump, which forces the gasoline into the generator tube. Air enters a separate tube and is mixed with the vaporized gasoline in mixing tubes. The air and gas mixture then goes to the burners, where it is lighted. Each burner is fitted with a *mantle*, which is a network made of oxides of two rare metals. This mantle gives a bright, white light when it is made very hot by the flame.

HOW ARE GAS BURNERS REGULATED? Most gas burners work like a burner invented about seventy years ago by a German scientist named Robert Bunsen and now used largely in scientific laboratories. Let us see how a Bunsen burner works.

*Experiment 24.* HOW DOES A BUNSEN BURNER WORK? (*a*) Take a Bunsen burner apart by unscrewing the barrel (Figure 68). Find a little hole through which the gas comes. Connect the bottom part of the burner to a gas-jet with a rubber tube. Turn on the gas just a little and light the stream of gas that comes out through the small opening. What color is the flame? Turn on the full pressure of the gas? What happens?

*b*) Shut off the burner and put the parts together. Turn on the gas and light it at the top of the barrel. Open and close the holes at the bottom. How does mixing air with the gas change the color of the flame? Can you explain why the color changes?

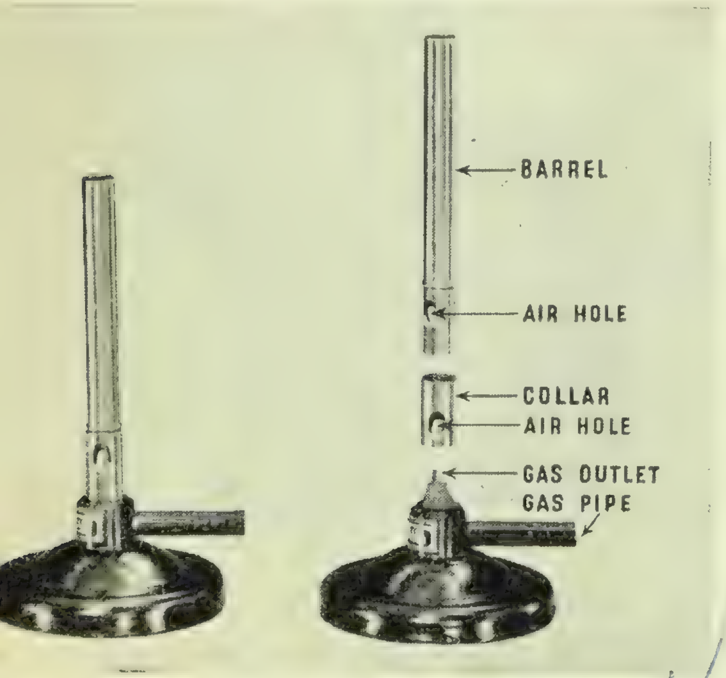


FIG. 68. Experiment 24

c) Find out what part of the flame is hottest. To do this, get a piece of iron-screen wire or a wire gauze used to put under flasks while they are heating. Light your burner and close the holes. Put the screen into the bottom of the yellow flame. Move it very slowly up through the flame. Watch the color of the wires. What is the hottest color they show? Where do they show this color?

Now make the flame blue and repeat the test with the wire screen. In which flame do the wires become hotter? Is there more gas burning in the hotter flame? What causes the difference? Which flame would you use to melt a glass tube? Where in the flame would you hold the tube?

d) Turn the gas down to make a medium-sized yellow flame. Hold a white dish in the upper part of the flame. The black material you get on the dish is carbon. Try a clean dish in the blue flame. Do you get carbon on it? Why?

Your experiments show that we get the cleanest and hottest gas flame when we mix the right amount of air with the gas before we burn it. If you look at the burners in a kitchen gas stove, you will find that they are arranged almost exactly like our laboratory burners. If you take a burner apart, you will find a small hole at the end of the pipe where the gas comes in. Around this is a

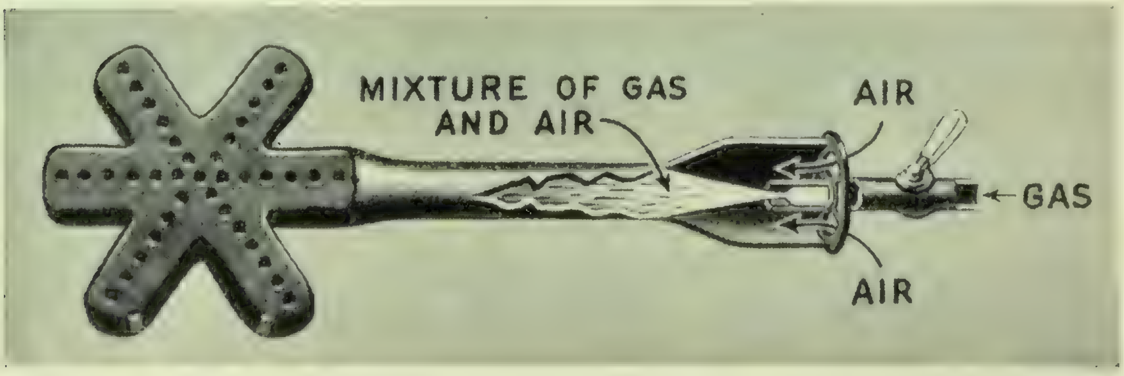


FIG. 69. In a kitchen gas-stove burner the gas enters through the gas line and is mixed with air in the mixing chamber.


FIG. 70. This is called a *gun-type* oil-burner. In the upper left corner is shown the construction of the nozzle for spraying oil and air.

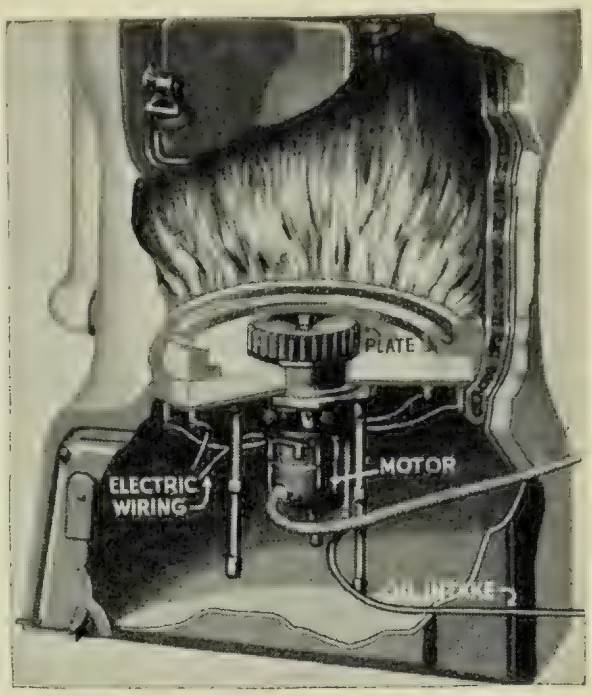


FIG. 71. A *rotary-atomizer* type of oil-burner throws oil and air against the sides of the furnace where it is set on fire by an electric spark.

large pipe with openings to let in air. These openings have shutters that can be turned to let in just the right amount of air. If you have a gas-burner at home, light it, and notice the color of the flames.

HOW ARE THE FIRES IN OIL-BURNING FURNACES REGULATED? To burn oil without smoke, the oil must first be changed into a very fine mist, or vapor. One common way of doing this is to pump the oil through a tiny nozzle under high pressure. This breaks the oil into a fine mist (Figure 70). At the same time an electric fan blows a current of air past the nozzle. An electric spark sets the mixture of fuel and air on fire, and it burns until a thermostat stops the motor that runs the pump and fan.

Another kind of oil-burner has a plate, or disk, in the centre of the furnace (Figure 71). An electric motor whirls the disk at high speed. The oil comes up into the disk and is thrown outward against the sides of the furnace, where it burns. The whirling disk also acts like a fan to bring air into the furnace.

*Self-Testing Exercises.* 1. Explain in one or two sentences how all kinds of fires are regulated.

2. What kinds of heating devices are used in homes? How is each one regulated? Explain carefully.

3. Compare the regulation of a coal fire with the regulation of a gas fire.

4. Explain why the air must be carefully regulated in a gasoline lamp in order to get the best light from the mantle.

*Problems to Solve.* 1. If the cost of fuels were the same for the amount of heat secured, what kind of fuel would you prefer to use? Give your reasons.

2. Find automatic coal-stokers and oil-burners on display in stores. Learn how they work.

3. Make a drawing of the furnace in your home, labelling all of its parts. Some furnaces may be regulated from upstairs by means of a chain. If your furnace is regulated in this fashion, explain how the chain operates the regulating devices.

4. If you have a gas stove in your home, make a drawing of the burner. Show the control valve, air holes, mixing chamber, and places where the gas burns. If your stove has an automatic lighter, explain how it operates.

5. A fire in a furnace will burn more satisfactorily if some of the ashes are left on the grate. Why?

6. Write to the manufacturer of gasoline lamps or kerosene lamps, asking for drawings and descriptive material that explain the operation of the lamp. Make an outline of what you learn by reading the material you receive, and be ready to present it to the class.

## ¶ 4. How do we prevent and extinguish accidental fires?

CANADA LOST $50 A MINUTE by fires in the year 1938. If you earned $50 every time the minute-hand of your clock passed a mark on the dial, day and night, how rich you would be! But imagine losing money at that rate. Homes and schools and churches, factories and stores, forests and wild life are going up in smoke. Carelessness or ignorance on the part of someone causes most of the fires that destroy lives and property. Many things are being done to stop this terrible loss from fire. The use of building materials that will not burn, greater care, and better ways of fighting fires have helped reduce the loss to

one-half what it was in 1926. Table 8 gives the most common causes of the fires that need never happen.

TABLE 8. CAUSES OF PREVENTABLE FIRES

1. *Careless Handling of Fire and Fire Materials*

Throwing lighted matches on combustible materials.
Allowing trash piles to accumulate.
Dumping ashes that contain live coals.
Overheating stoves.
Burning out of chimneys containing much soot.
Rolling up oily rags (spontaneous combustion).
Storing coal where little air circulates (spontaneous combustion).
Storing damp hay (spontaneous combustion).
Lighting matches in a garage.
Bringing lighted matches near gasoline tanks.
Using gasoline or benzene to clean clothes.
Filling kerosene or gasoline lamps while using a lamp for light.
Placing a lamp or a lantern where it can be upset easily.
Starting fires in stoves with kerosene or gasoline.

2. *Electricity*

Driving nails into electric wires and causing "short-circuits."
Using wrong kind of fuse for the kind of circuit.
Attaching too many electrical devices at the same time.
Using wires too small for a heavy current.
Rubbing the insulation off wires.
Wiring buildings without proper insulation.

3. *Faulty Construction of Heating Devices and Buildings*

Defective oil stoves.
Leaking gasoline tanks.
Stoves placed over wood or carpets.
Fireplaces without screens.
Poorly constructed flues and chimneys.
Running heating pipes near combustible materials.
Using combustible materials for buildings.

HOW ARE ACCIDENTAL FIRES PREVENTED? Each cause of a fire in Table 8 did one thing: it allowed some combustible material to get too hot. There is danger of fire whenever we let combustible material get next to something hot and whenever we put something hot on a combustible material.

The first important way of preventing fires is to keep fire and hot objects away from combustible materials. All ashes should

be put in metal cans or in brick or concrete bins. Ashes often have live coals in them. All lighted cigars and cigarettes should be laid on metal, porcelain, or glass. Fires should be built only on soil, metal, stone, or brick. Buildings that are close to each other should be built only of fireproof materials. Waste paper and rubbish should never be stored near furnaces or stoves.

FIG. 72. One should *never* use gasoline, benzene, naphtha, or alcohol near a fire, as this woman is doing. (Photo from Chicago Chapter of American Red Cross)

Electric wires should be properly connected so that they will not overheat, and covered so that they do not touch combustible materials. Never pour kerosene on a smoldering fire. Never use lighted matches or candles when you are trying to find gas or gasoline leaks. Flashlights are inexpensive and safe.

Spontaneous combustion, in which chemical action produces heat, is a more common cause of fire than most people suppose. Each year fires started in this way cause losses of about $12,000,000. The most frequent cause of spontaneous combustion is the storing of oily rags, mops, or other materials. As you learned on page 112, such oils slowly oxidize and heat the materials enough to start them burning. Other fires are started by the spontaneous heating of sawdust, grain, charcoal, soft coal, wool, and hay. Such materials should not be stored in large masses unless they are so well ventilated that the heat can escape.

*Self-Testing Exercises.* 1. From Table 8 make a list of the ways you think a fire might get started in your own home. Opposite each item in your list tell how a fire from that cause can be prevented.

2. What should be done with oily rags and mops to prevent spontaneous combustion?

*Problems to Solve.* 1. What are the most common causes of fires in your city or neighborhood? Decide how you can get the information, and then get it.

2. What precautions are taken in your city to prevent fire?

HOW DO WE EXTINGUISH FIRE? In spite of our care some accidental fires will get started. Thus, everyone should be ready for action. If you live in a town or city, be sure that you know how to send a fire-alarm. If a fire starts that you cannot stop, you should call for help immediately.

What you have learned about fire should help you put out fire or keep it from spreading. A fire that you cannot put out may often be slowed down and kept in one room for a time by shutting doors and windows. This shuts off some of the oxygen and keeps the hot gases from spreading the fire rapidly. Smothering a fire, that is, shutting off the air, is usually the most practical way of stopping it. Woollen rugs, blankets, and coats burn slowly and may be thrown on a small fire or wrapped around a person whose clothing has caught fire.

Water and the steam it produces will smother a fire. Water also cools things until they will not burn. But pouring water on gasoline and oil is useless. These materials float on the water and are spread by water without being extinguished. For small gasoline or oil fires use sand, dirt, or woollen materials.

Cutting off the supply of fuel is, of course, another way of stopping a fire. Quick action to shut off gas or flowing gasoline is often necessary to prevent serious fires. Forest fires are sometimes fought by clearing a space ahead of the fire or by starting small "backfires" that may be kept under control while they burn a strip around the main fire. In cities the firemen sometimes dynamite buildings to stop fire from spreading.

HOW DO CHEMICAL FIRE-EXTINGUISHERS WORK? You will often see small hand fire-extinguishers ready for use in buildings or other places. You should know how they work, so that you can use them more quickly and effectively. A kind of chemical extinguisher we often see in school buildings is a brass tank hung on the wall (Figure 73). Attached to the top of the tank is a rubber hose with a nozzle. The directions on the side read something like this: "To start, turn bottom up." This kind of ex-

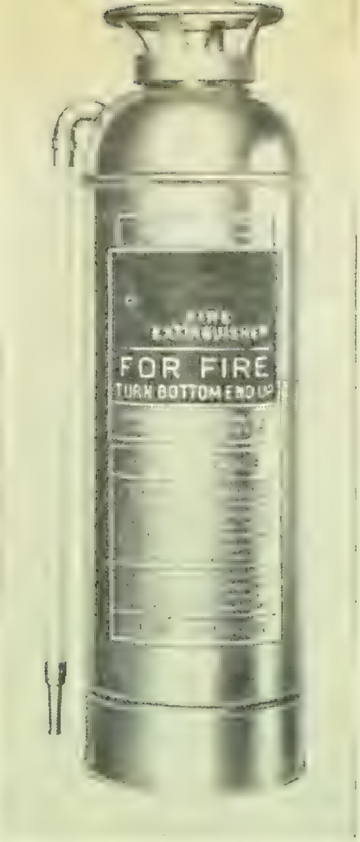


Fig. 73. A carbon-dioxide fire extinguisher (Pyrene Co. photo)

Fig. 74. Apparatus for part a of Experiment 25

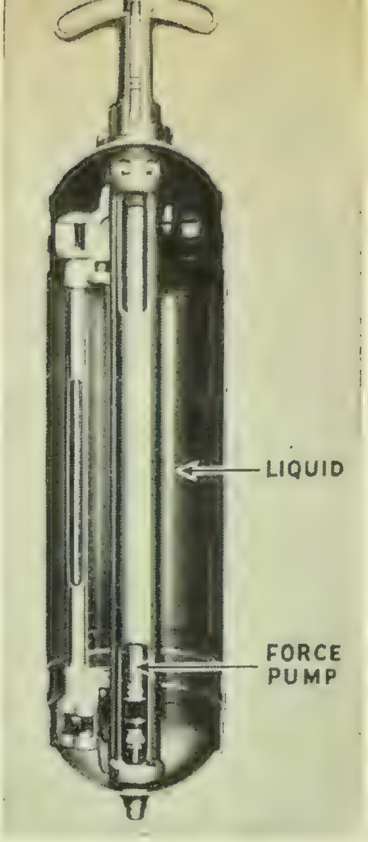


Fig. 75. A carbon-tetrachloride extinguisher (Pyrene Co. photo)

tinguisher is really just a tank of water with chemicals kept separate from the water. When it is turned upside down, chemical action makes the water squirt from the hose.

*Experiment 25.* HOW DOES CHEMICAL ACTION PUSH THE WATER OUT OF AN EXTINGUISHER? (*a*) Put some water in the bottom of a jar. Dissolve about as much baking-soda (sodium bicarbonate) in the water as it will hold. Now pour some vinegar or dilute sulphuric acid into the soda solution. What happens? The gas formed is carbon dioxide. Lower a burning candle into the jar. Explain the results.

*b*) *Teacher demonstration.* Arrange a milk bottle or other wide-mouth bottle as shown in Figure 74. Put a strong solution of baking-soda in the large bottle, and a fifty-per-cent solution of sulphuric acid in the small bottle. *Wire the stopper in securely.* Then turn the bottle upside down over a sink or bucket. (*Caution:* Do not get the solution on your clothes.)

If you wish, attach a rubber tube with a glass nozzle and start a small fire in a sink or outdoors. Then put out the fire with the model extinguisher. Why does the water squirt out of the extinguisher?

The carbon-dioxide extinguisher is nearly full of a solution of baking-soda. A bottle in the top of the tank contains concentrated sulphuric acid. A lead stopper fits loosely in the bottle. When the tank is turned upside down, the stopper falls out, and

the acid mixes with the soda solution. A chemical action immediately makes a large amount of carbon dioxide. This gas forces the water out through the hose. The water lowers the temperature of the burning materials and cuts off the supply of oxygen. The carbon dioxide also helps to cut off the oxygen supply because it is about one and one-half times as heavy as air. In a closed room where there are no currents of air, the carbon dioxide may be of considerable value in extinguishing a fire. In open spaces the carbon dioxide may be carried away by wind, but the water would put out a small fire.

Another common kind of extinguisher is smaller than the carbon-dioxide extinguisher, and the directions tell you to work it like a pump (Figure 75). This kind of extinguisher usually contains a liquid called carbon tetrachloride, or a mixture of carbon tetrachloride with something else.

*Experiment 26.* HOW DOES CARBON TETRACHLORIDE PUT OUT A FIRE? (a) Pour two or three tablespoonfuls of carbon tetrachloride (or "Carbona" cleaning fluid) into a deep pan. Cover the pan loosely for ten minutes to allow part of the liquid to evaporate. Set a short lighted candle in a large beaker. Pour the vapor (not the liquid) from the pan into the beaker. Explain why the candle goes out. Try to light the candle again without taking it out of the beaker.

b) *Teacher demonstration.* Set a small dish of gasoline or kerosene in a large flat pan. If you have some asbestos, put it under the pan. Light the gasoline or kerosene. Pour water on the burning gasoline until the dish "runs over." What happens? Now pour some carbon tetrachloride on the burning gasoline. Why does the fire go out?

This experiment shows you how carbon-tetrachloride vapor puts out a gasoline or oil fire. Carbon tetrachloride changes to a vapor quickly when heated. This vapor is very much heavier than air. Therefore, when carbon tetrachloride is squirted on a fire, the heavy vapor settles down over the burning material and keeps the air away long enough to stop the fire. Extinguishers that use this chemical are small and easily carried in trucks and automobiles; therefore they are convenient to keep at hand. Furthermore, the liquid will not freeze in cold weather.

Another kind of extinguisher that is valuable for oil fires pours or throws a foam on the fire. This foam is made of bubbles of carbon dioxide. The foam of carbon-dioxide bubbles floats on the gasoline or oil and keeps the air away. The foam is made by mixing a solution of baking-soda and extract of licorice root with a solution of aluminum sulphate. The carbon dioxide is formed by chemical action between the soda and aluminum sulphate. The extract of licorice root helps make tough bubbles to carry the carbon dioxide to the fire.

Fig. 76. This man is putting out an oil fire with a tank of liquid carbon-dioxide. Notice that he is directing the spray at the place where the burning is taking place rather than on the flames above. (Pyrene Co. photo)

You may see other kinds of extinguishers. If they are near where you study, work, or play, be sure to read the directions on them. You will then know how to use them in case of fire. Extinguishers, roofing materials, oil-burners, and electrical devices must be safe and reliable for preventing or extinguishing fires. Any such article offered for sale must be inspected by the Canadian Engineering Standards Association at Ottawa, or by the National Research Council at Ottawa; any article bearing the label of the Underwriters' Laboratories is approved also. Examine the extinguishers in your school for this label.

*Self-Testing Exercises.* 1. Find all the different devices for extinguishing or fighting fire in your school. Make a list of them.

2. Explain how a carbon-dioxide fire-extinguisher puts out a fire. Tell why the water comes out and why it puts out a fire.

3. How does a carbon-tetrachloride extinguisher put out a fire? Why is it better than water for a gasoline fire?

4. If a fire started where there were no extinguishers, what are the things you might do?

*Problems to Solve.* 1. Find out how the fire department in your city or town is equipped to fight fire. Firemen are usually glad to explain about their apparatus.

2. What are some of the reasons why fires are often very hard to put out?

3. Make a map showing the location of fire plugs and fire-alarm boxes in the immediate neighborhood both of your home and your school.

## Looking Back at Unit 4

1. In this unit you have learned some more science principles that you can use to explain everyday problems. Make a list of them, writing them as sentences.

2. Show that you know the meaning of the following words:

| | | | |
|---|---|---|---|
| *mechanical energy* | *mantle* | *oxidation* | *tinder* |
| *kindling temperature* | *combustible* | *thermostat* | *oxide* |
| *spontaneous combustion* | *energy* | *ashes* | *coke* |
| *chemical energy* | *burning* | *damper* | *draft* |

## Additional Exercises

1. Make a study of how to prevent loss from fire. You can get much helpful material by writing to the Dominion Fire Prevention Association, Ottawa, or the (International) National Fire Protection Association, 60 Batterymarch St., Boston, Mass.

2. Light a Bunsen burner and bring an iron or copper screen down on the flame. Why does the flame not go through the screen? Turn out the burner. Then turn on the gas, hold the screen above the burner, and bring a lighted match to the gas above the screen. What happens? Can you explain it?

3. Read in reference books about peat and lignite. What are they, and what are they used for?

4. If a kerosene lamp begins to smoke, how do you think the smoking could be stopped?

5. Collect samples of the different kinds of fuels sold in your community. Compare their characteristics. If possible, find out their heat value and see which kinds one should buy to get the most heat for the least money.

6. Study the photo flash-bulbs used by photographers. The bulbs are filled with pure oxygen. What is the combustible material? How is it "set off"? What is the white material inside the glass after the bulb has been used?

7. How can a city reduce the amount of smoke from the chimneys of its homes, factories, and office buildings? If your city has a "smoke-abatement" department, learn what it is doing.

8. Pails of sand are sometimes kept in garages and chemical laboratories. What is the use of the sand?

9. Why do you blow on a match to put it out and blow on a smoldering fire to make it burn?

10. Why do factories with large steam power plants often have very tall chimneys?

11. Write to the manufacturer of mantles, and obtain information on how the mantles are made and what materials are used. You may find the information in a textbook of chemistry.

12. Make a class collection of newspaper clippings about fires. Group the fires according to causes and keep a record of the lives lost and the property destroyed whenever this information is given.

13. About how many cubic feet of oxygen are there in your schoolroom?

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In Unit 1 you learned that there are hundreds of thousands of kinds of living things. Study this picture. What you see are tiny plants and animals in one drop of water, magnified hundreds of times. The animals are so different from the animals you know that you would not recognize them. In this unit you will learn how these tiny creatures are like yourself and like all other living things. (Pinney Science photo)

# UNIT 5

# How Are All Living Things Alike?

## Looking Ahead to Unit 5

So far in this book most of your study of science has been about things that are not alive. But all around you is a world of living neighbors. We cannot get along without these plants and animals. What are they like? How are they made? Are such things as chemical changes and heat important to them? Of course, things that are alive are made of matter, and they are affected by heat and cold. They use solutions, and they have many different chemical substances in them. But living things are different from things that are not alive, and scientists study them just as carefully as they study non-living things. You are now going to think about some of the living things of the world, including yourself. In other words, you are going to study that part of science known as biology.

In Unit 1 you learned that there are many different kinds of living things. Did you ever wonder what "life" is? A mushroom, an oak tree, a fish, and yourself are alive. Yet they are very different in appearance, and they are very different in many of the things they can do. The more you think about different kinds of living things, the more likely you are to see the great differences among them. Yet there must be something that makes them "alive." What does "being alive" mean? Perhaps if we can find out how the oak tree is like the squirrel that climbs the tree to get an acorn, we shall know something about what it means to be alive. Certainly we shall learn the ways in which the tree and the squirrel are different from soil, water, and air, which we know are not alive.

Before you begin your study of this unit, suppose you think a while about these questions: What things does a tree need that I need? What things can a tree do that I can do? What kind

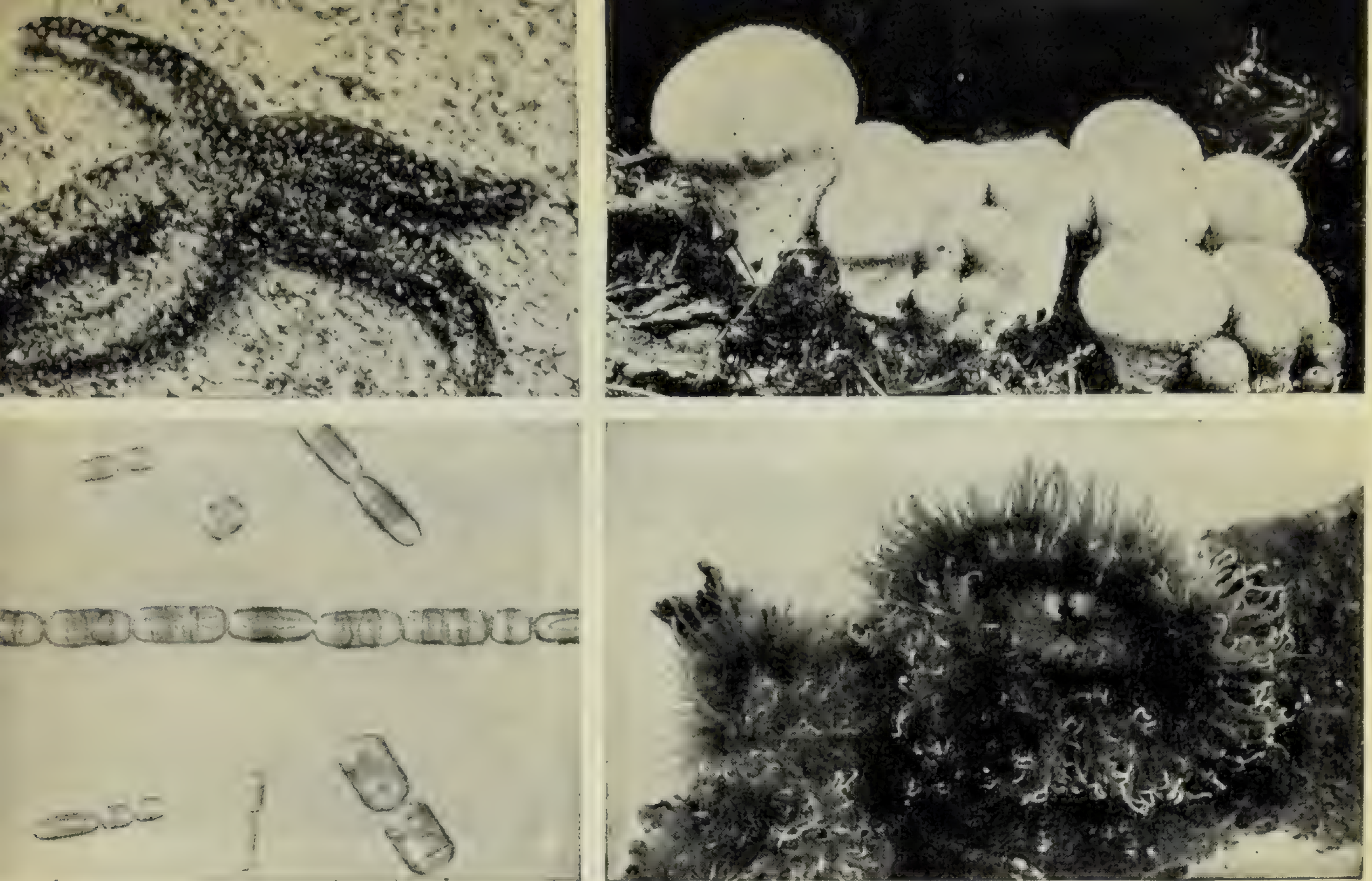

FIG. 77. Here are four different kinds of living things: (*top*) starfish, puff balls; (*bottom*) diatoms (seen through a microscope), sea-anemone. Which ones do you think are animals, and which ones are plants? (*Top*, Brownell and American Museum photos; *bottom*, Chicago Natural History Museum and Brownell photos)

of living thing makes all the food for all the other living things of the world? While you are thinking about these questions, it would be a good plan to review what you learned about elements, compounds, and chemical change in Units 2 and 3. You will need these science principles to help you understand how all living things are alike.

## 1. How are plants and animals alike in what they do?

WHAT CAN ALL ANIMALS DO? It is very important to know what living things do. Let us begin by thinking what animals do. Think of any kinds of animals you please—cats, dogs, flies, spiders, earthworms, fish, birds, butterflies, squirrels, people. What can they all do? Probably the first thing that comes to your mind is that they all can move about from one place to another by crawling, walking, swimming, or flying. Yet there are some animals, such as sponges and sea-anemones (Figure 77), that cannot move about. However, they can all move some parts of their bodies.

FIG. 78. Animals are affected by various kinds of *stimuli*. This baby rabbit is smelling the odor of clover, one of its favorite foods. We say that the odor is a *stimulus*. It makes the rabbit do something. He moves toward the clover and may eat it. (Chace photo)

Here are six things that all animals can do: (1) move at least a part of their bodies, (2) take in food, (3) breathe in oxygen, (4) give out waste materials from their bodies, (5) produce young animals, (6) grow when young until they are about the size of their parents.

Animals can do another very important kind of thing. They can act in the correct way when messages come to them from their surroundings. What kinds of messages do animals receive? A light message comes to their eyes from each thing they see. Odors tell them when enemies or friends or food substances are near. Sounds are also important messages. We can talk about these different kinds of messages more easily when we have a special word for them. Biologists call all these different kinds of messages *stimuli* (singular, *stimulus*).

The way an animal acts when it receives a stimulus is called a *response*. Most animals respond to stimuli from their enemies by running away, hiding, or fighting. When they are hungry, they respond to the stimuli from food by going toward it and eating it. All animals respond to stimuli in some way. This is the seventh thing animals do.

Can non-living things do the important things animals do? If you will think carefully, you will discover that some non-living things can take in oxygen and give out wastes. Others can move in response to stimuli, and still others can grow. For instance, stoves, automobiles, and locomotives take in oxygen and give out wastes. An automobile, a toy train, or a gun responds to the stimulus of a push or pull on a lever; that is, each does something.

Yet you will agree that these things are not done in the same way by an automobile as by an animal.

Did you know that there are a few things that grow even though they are not alive. The little sharp-cornered pieces of sugar, salt, and other chemical substances are called *crystals*. Crystals can grow. You can watch them grow when you do the next experiment.

*Experiment 27.* HOW DO CRYSTALS GROW? Obtain crystals of alum, copper sulphate, or sodium hyposulphate ("hypo"). Select one of these substances, powder some of it, and dissolve it in half a glass of warm water by stirring. Add enough powdered crystals so that after vigorous stirring there are some crystals left undissolved at the bottom of the glass.

Allow the solution to settle for fifteen minutes, and then pour most of the clear liquid above the undissolved crystals into a clean glass. Suspend a crystal of the substance by a thread in the clear solution. Set the glass in a quiet place for a few days. Does the crystal grow? How?

A crystal gets larger by adding new layers of the same material on the outside of the crystal. This is quite different from what happens when a living thing grows. A squirrel eats acorns and changes them into bone and muscle and skin and fur. This change takes place inside the body of the squirrel. Thus living things grow from the inside. When living things grow, their food, which is not alive, is changed to living material. This new living material is added to the body; thus the body of the living thing gets larger.

You can see that *all* animals move some parts of their bodies, use food and oxygen, and give out waste materials from their bodies. They produce young, grow, and respond to stimuli. We may find a few non-living things that do one or another of these things, but no non-living thing can do all of them.

HOW ARE PLANTS LIKE ANIMALS? Can plants move? Certainly they cannot run around or hide and leap out to catch other things for food. Yet when we very carefully mark the place where the tip of a vine is and come back a few hours later, we often find that the tip has moved. Have you ever seen a motion-picture of a baby plant getting out of the seed or of a flower opening? If so,

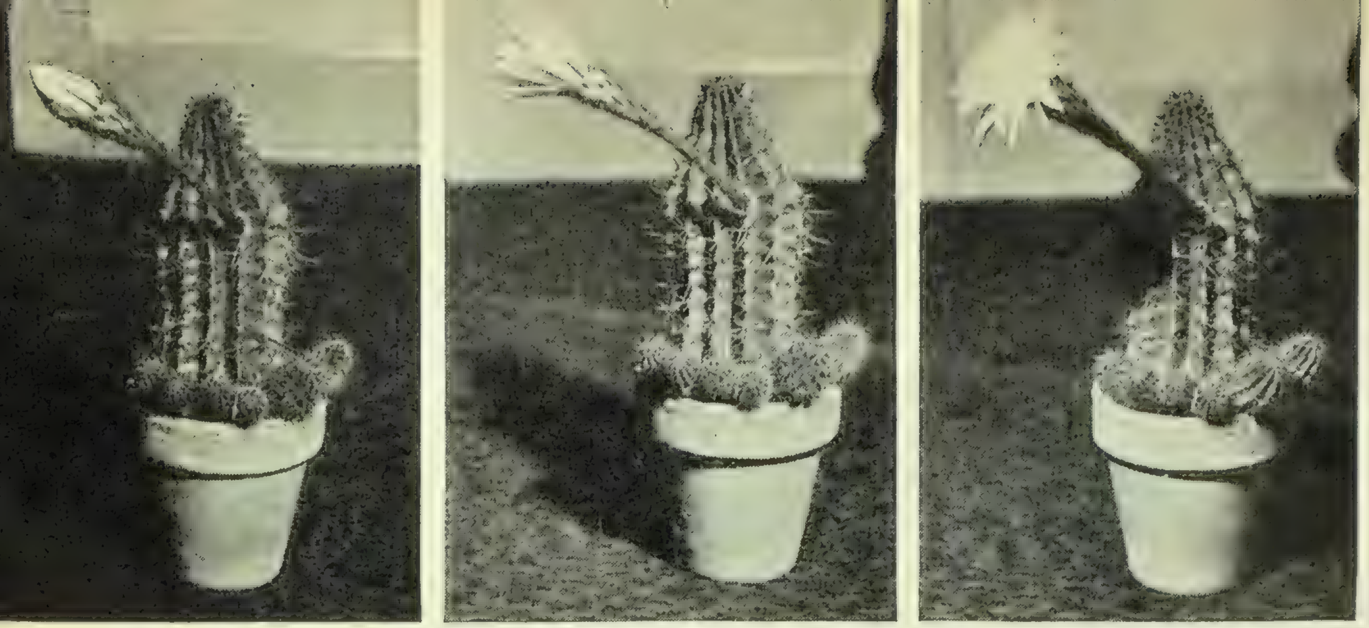

Fig. 79. This series of pictures shows the night-blooming cereus, a member of the cactus family, coming into flower. It took one hour and a half for the bud to open into a full flower. (W. B. Hansford, Jr. photo)

you have seen that plants do raise and lower their leaves and petals and wave their tips about in the air.

Do plants use food? You are not very much afraid that a plant might eat you, even in a tropical jungle. Yet plants must have some way to keep alive and to grow, just as animals must. Therefore plants must have food. In Problem 4 you will learn how plants get their food. Do plants breathe? They surely do not have lungs or gills. They do not make any breathing movements that we can see. However, careful tests show that plants take in oxygen from the air through their leaves. They must have oxygen to keep alive. When fields of wheat and corn are covered by a flood for several days, the plants die or are badly injured because the water keeps the air away from their roots and leaves. Thus some plants can be drowned when they are covered by water, just as animals can be drowned.

Do plants give off waste materials? You can do an experiment that will help you answer this question.

*Experiment 28.* DO PLANTS GIVE OUT CARBON DIOXIDE AS ANIMALS DO? (*a*) Arrange a test-tube, stopper, and tubing as shown in Figure 80. Put some small pieces of limestone into the test-tube. Fill a second test-tube half full of limewater that your teacher will have for you. Now pour some dilute sulphuric acid on the limestone. The limestone will give out bubbles of carbon dioxide ($CO_2$) when an acid is poured on it. Immediately put the stopper in that test-tube. Let the carbon dioxide gas from the limestone and acid bubble through the limewater. The limewater should then become milky white.

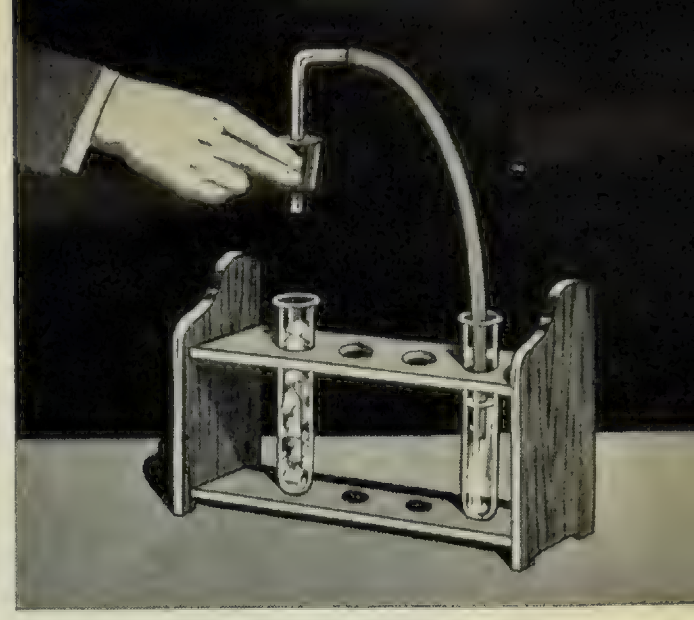

FIG. 80. Apparatus for Experiment 28a

*b*) Blow your breath slowly through a glass tube into some limewater. Does your breath have carbon dioxide in it?

c) Get two glass or stone jars large enough to cover a potted plant. The jars should have covers that fit rather closely. Into Jar A put a vigorous plant. Beside it, inside the jar, set a small glass of limewater. Put the cover on the jar. Into Jar B put a pot of moist soil the same size as the one with the growing plant. Put beside it a glass of limewater and cover the jar as you did Jar A.

Leave both jars for twenty-four hours. If the jars or covers are glass, the jars should be in a dark place. After twenty-four hours look at the limewater carefully. Which limewater has more white material in it? Which jar had the more carbon dioxide? Where did it come from?

In this experiment the jars were arranged so that they were different in only one way: One jar had a living plant in it that the other jar did not have. Almost always the limewater in the jar containing the plant has the more white material in it. The only reasonable explanation is that the plant gave out some carbon dioxide during the time it was in the jar. In part *b* of the experiment you also found carbon dioxide in your breath. Both plants and animals give out carbon dioxide as a waste material.

Of course you know that plants make other plants like themselves, just as animals produce young animals. Oak trees have acorns that can grow into more oak trees. And that yellow nuisance of the lawn, the dandelion, has hundreds of seeds that go floating through the air to start baby dandelions growing everywhere! Some plants, such as mosses and ferns, do not have seeds, but they produce young plants in one way or another.

And how plants can grow! They grow faster than animals, and some of them grow larger than any other living things. Trees are the largest plants, and the great redwood trees of California have grown until they are the largest living things on earth, perhaps the largest that ever existed.

Do plants respond to stimuli? Have you ever seen a "sensitive" plant? This plant is unusual because its leaves fold together and

FIG. 81. How the sensitive plant responds to the stimulus of touch

droop whenever the plant is touched or shaken (Figure 81). Yet we do not need to have a sensitive plant to see that plants can respond to stimuli. Have you ever seen how the tip of a young sunflower plant turns toward the sun as the sun moves across the sky? Or how the flower of the four-o'clock closes after dark? Or how the leaves of clover fold at dusk? The plants are all responding to the stimulus of the sun's rays. Roots of plants respond to the stimulus of gravity by growing down into the soil, while the branches and leaves grow upward into the light and warmth of the sun. Plants do respond to many stimuli.

Now you can see that a plant and an animal are alike in many ways. They both grow; they both use food and oxygen; they both give out wastes; they both produce young that grow to be like their parents; they both can move either all of their bodies or parts of them; and they both respond to stimuli. Perhaps "being alive" really means doing these things.

*Self-Testing Exercises.* 1. List the seven things that both plants and animals do. Then give an example of your own to show how each activity is carried on by animals and by plants, as shown below.

| ACTIVITIES OF LIVING THINGS | ANIMAL EXAMPLES | PLANT EXAMPLES |
|---|---|---|
| 1. Producing young . . . | Turtles lay eggs from which young turtles hatch. | Young potato plants grow from potatoes that are put into the ground. |
| 2. Etc. . . . . . . . . | | |

2. What is a stimulus? Give three examples.

3. How are non-living things different from living things in what they are able to do?

*Problems to Solve.* 1. Give as many ways as you can in which some one animal and a locomotive are alike. Why cannot a locomotive be called a living thing?

2. Plan and carry out some observations to see if you can notice movements of plants or parts of plants.

3. Plan one experiment to show that a plant responds to light and another experiment to show that roots of plants grow down and stems grow up.

4. Read in books to find out what kinds of animals cannot move from one place to another.

5. Write a paragraph telling how animals are different from plants.

## ¶ 2. What chemical substances are living things made of?

IN UNIT TWO YOU LEARNED that everything is made of chemical elements. There are less than 100 of these elements, and all matter is made of these different elements. Even though they seem very different from each other and from non-living things, plants and animals must be made of elements. Are all the different elements found in the bodies of living things? If they are not all found in living things, which elements are living things made of?

You have also learned that compounds are substances made up of two, or more than two, elements. These compounds generally look different from the elements that are in them. What compounds are found in plants and animals? Are they special kinds of compounds? Are the compounds of which plants are made different from those in animals?

WHAT ELEMENTS ARE FOUND IN PLANTS AND ANIMALS? Chemists have worked out many tests to find what elements are in the body of a plant or an animal. Chemists are also able to find out how much of each element there is. Let us first see what chemists have learned about the elements in the human body. What elements would you expect to find most plentiful? How many elements would you expect to find? In Unit 2, page 51, you read about some of the substances found in the body of a man. You may be interested in reading that list again. Table 9 gives a more exact and complete list of the elements found in the

human body. It also tells the number of pounds of each element that would probably be in the body of a person who weighs 100 pounds.

TABLE 9. COMPOSITION OF A 100-POUND PERSON

| ELEMENT | POUNDS | ELEMENT | POUNDS |
|---|---|---|---|
| Oxygen (O) | 65.0 | Chlorine (Cl) | 0.15 |
| Carbon (C) | 18.0 | Magnesium (Mg) | 0.05 |
| Hydrogen (H) | 10.0 | Iron (Fe) | 0.004 |
| Nitrogen (N) | 3.0 | Copper (Cu) | Trace |
| Calcium (Ca) | 2.0 | Iodine (I) | Trace |
| Phosphorus (P) | 1.0 | Fluorine (F) | Trace |
| Potassium (K) | 0.35 | Manganese (Mn) | Trace |
| Sulphur (S) | 0.25 | Silicon (Si) | Trace |
| Sodium (Na) | 0.15 | Zinc (Zn) | Trace |

You will notice that six elements make up almost the whole body. Our bones are made largely of calcium and phosphorus. The rest of our bodies is made up chiefly of four elements: oxygen, carbon, hydrogen, and nitrogen. You should remember the names of these four elements; they are the elements that take part in almost all the chemical changes in living things.

The last twelve elements in the list do not seem to be very important. All of them put together do not make much more than a pound. There is so little of six of them that the weight is not even given. Yet, if any one of these elements was missing, we probably could not go on living. The elements in the body of any common animal are very nearly the same as those in the body of a man. In a very different animal we would find more of some one element. Some sponges, for example, have much silicon in them. Chemical analysis of plants shows the same elements that we find in animals. Every element found in the bodies of animals is also found in plants. And the four leading elements in plants are the same four leading elements that are found in our own bodies.

The element carbon makes one of the most important differences between living things and non-living things. Less than one five-hundredth part of the rock and soil on the outside of the earth is carbon. Yet almost one-fifth of the material in all living things is carbon. In proportion to their size, plants and

animals have about one hundred times as much carbon as non-livings things like rock and soil. In all plants and animals carbon is always the second element in amount. It makes up nearly one-fifth of the human body.

WHAT COMPOUNDS ARE IMPORTANT IN PLANTS AND ANIMALS? Suppose a chemist should get together the elements he would need if he could make a man weighing 150 pounds. These elements, under ordinary conditions, would fill a room sixteen feet wide, sixteen feet long, and sixteen feet high. How can all this raw material go into the body of one man? It can do so because hydrogen, oxygen, and some of the other elements in the human body are gases. These gases fill up a great deal of space when they are in the form of separate elements. But when the gaseous elements are changed into the compounds found in the body, they become liquids or solids. Then they take up much less space.

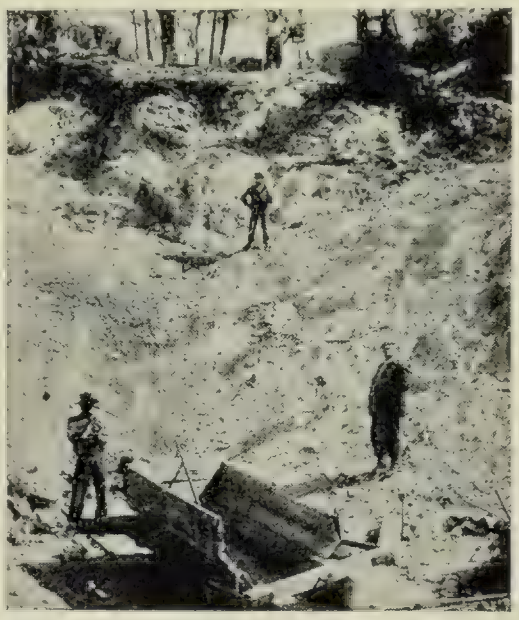

FIG. 82. This picture shows a large phosphate mine. Phosphate is a rock that is found just under the soil. It is dug out and ground up to be used as food-making material for plants.

One of the compounds you know most about makes up about two-thirds of the weight of plants and animals. That compound is water ($H_2O$). Water makes our blood liquid. It forms most of the perspiration, and it carries away important wastes from our bodies. It does many other useful things for us as well as for plants and animals.

Our bodies, and those of other animals, contain small amounts of salt ($NaCl$). You have probably noticed that sweat and blood taste salty. If some of the material from your stomach has ever come up into your mouth, you have noticed that it tastes sour. That sour taste is the taste of hydrochloric acid ($HCl$). This compound of hydrogen and chlorine must be in our stomachs to help digest our food. The hard part of our bones is largely a compound called calcium phosphate [$Ca_3(PO_4)_2$]. This com-

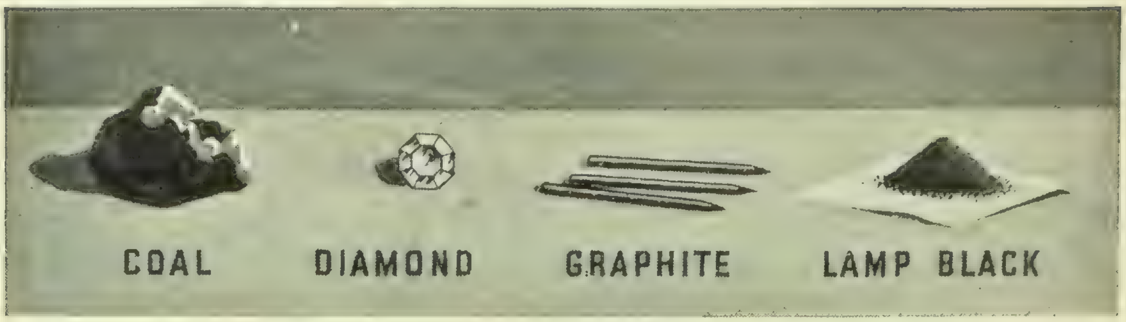


FIG. 83. Can you believe that all of these are different forms of one element, carbon? Carbon is found in many different forms and in many different compounds. Probably it is the various compounds of carbon that make plants different from animals and each kind of plant and animal different from all other kinds.

pound contains calcium, phosphorus, and oxygen. Water, salt, hydrochloric acid, and calcium phosphate are rather common compounds; they are found in many places on, and in, the earth. In addition to these four compounds, there are a great many others that chemists have found in our bodies.

But the compounds that make plants and animals different from non-living things are the compounds of carbon. In some strange way carbon is different from all other elements. Carbon is found in about ten times as many different compounds as all the other chemical elements. Actually, there are thousands of different kinds of carbon compounds in the bodies of plants and animals. These carbon compounds produce the thousands of varied odors and tastes and colors of living things. It is these carbon compounds that make living things alike and also make them different.

*Self-Testing Exercises.* 1. Name the four elements found in largest amounts in the bodies of plants and animals.

2. What element found in the bodies of living things is different from all other elements? Give some reasons for saying that element is different.

3. What compound makes up most of the weight of plants and animals? What elements are found in this compound?

4. What parts of your body would be most harmed if you did not get enough calcium in your food?

5. How are plants and animals alike in the materials they are made of? Give as many different ways as you can.

*Problems to Solve.* 1. How do the chemical substances in living things differ from those in non-living things? Give as many ways as you can.

2. Plan and carry out an experiment to find how much water there is in some plant or part of a plant.

3. Find in some book a table that tells the percentages of the elements in the outer part of the earth. Make a circle graph to show the most plentiful elements. Color each of the elements differently.

4. What substance is used by living things in the form of an element instead of in the form of a compound? Tell several things you know about this element.

## 3. How are plants like animals in the way they are put together?

WHAT DOES A MICROSCOPE SHOW IN THE PARTS OF PLANTS AND ANIMALS? One way in which common plants and animals are alike is that both are made up of parts, or *organs*. A bean plant has roots, a stem, leaves, flowers, and, later, a pod with seeds in it. These parts of the plant are called its organs. A dog has legs, eyes, ears, nose, body, and tail. Inside the body you know that there are lungs, a heart, a stomach, and other organs. What are some of your organs?

When the microscope finally was invented, scientists began looking at the organs of living things. Then they found another way in which plants and animals are alike. Let us look at plants and animals as these early scientists did, to see what we can discover about the way they are made.

*Experiment* 29. WHAT DO PLANTS AND ANIMALS LOOK LIKE UNDER THE MICROSCOPE? (*a*) Look at the cut edge of the following things with a good magnifier (simple microscope): cork, tomato, apple, a maple twig, and a celery stalk. Use a very sharp knife, like a safety-razor blade, to make the cuts. Very thin slices covered with water on a small strip of glass will show best.

*b*) Now look at the slices under a compound microscope (low power). You can see the objects more clearly if you lay a very thin piece of glass on top of them. Look also at leaves of water plants and the tiny thread-like green plants that grow in water. Do the things you look at seem to be built in little sections? These little sections are called *cells*.

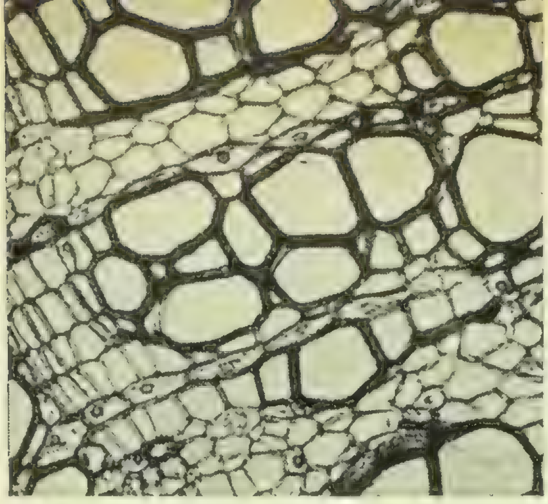

Fig. 84. A thin slice of wood as seen under a microscope (General Biological Supply House photo)

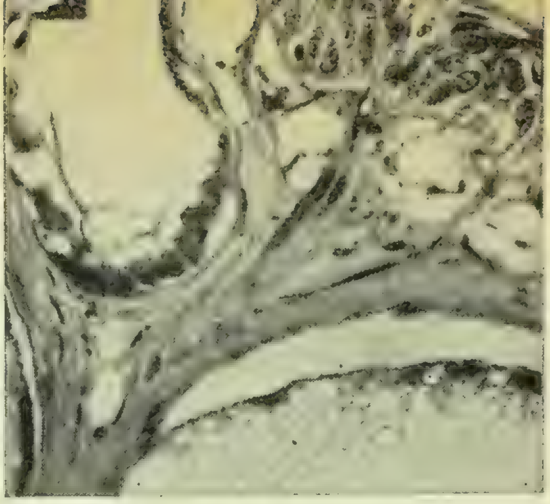

Fig. 85. A bit of the skin of a frog as seen under a microscope (General Biological Supply House photo)

c) With the compound microscope look at thin slices of the parts of some animals. You will need to use specially prepared slices of material fastened on little strips of glass. These are called permanent microscope slides. You can probably borrow some from a biology room in your school. Look at the skin of a frog, thin slices of the brain or spinal cord of some animal, the lining of a stomach or large intestine, and the blood of a frog or bird. Do they have little sections, or cells, in them, too?

Perhaps your teacher will show you how to scrape a little of the lining from the inside of your mouth and put it on a glass slide to look at. When you have a blister or when some skin peels from your body, put the skin in some water on a slide and see if you can find cells in it.

Imagine the surprise of Robert Hooke, an English scientist, when (about 1665) he looked at a piece of cork under a microscope. Hooke saw that the cork was made of tiny compartments, or hollow spaces with walls around them. These little compartments looked like the cells in a prison or in a honeycomb; so Hooke said that the cork was made of *cells*. Inside all living cells is a jelly-like material. We now know that this material in living cells is more important than the walls of the cells.

As time went on, more and more scientists saw cells in more and more living things. They did not see them in things that had never been alive. About one hundred years ago two European scientists, as a result of very careful study and research, said they thought that all plants and all animals were made of cells. They also thought that everything that living things make and do is made and done by these cells. We now know that they were right.

The bodies of all living things are made of cells like those you saw with your magnifier and microscope. When you know how to look for them, you can often see them without a magnifier in *pith* (the central part of plant stems) and in fruits. Your body, a squirrel, an oak tree, or any living thing you care to mention, is made of cells. These cells make up the body much as bricks or stones make up the walls of a building. But most cells are not non-living things like bricks and stones. They are alive and doing things. If your heart, your muscles, and your brain are made of cells, then the cells must be "beating," moving, and thinking. If the oak that grows from an acorn is made of cells, then cells must grow and multiply as the tree grows. That is what happens. The cells get larger, and they make new cells.

WHAT ARE CELLS MADE OF? If you have a compound microscope, use it to examine some cells more carefully than you did in Experiment 29 so that you can see the most important parts of cells.

*Experiment* 30. WHAT ARE THE PARTS OF CELLS? (*a*) If possible, your teacher will show you an ameba in a drop of water under a microscope. The ameba is just one cell. Can you see the clear, grayish material of which the animal is made? This is the living part of the animal, and it is called *protoplasm*. Watch the animal to see what the protoplasm is doing. Look for a darker, biscuit-shaped piece of the protoplasm inside the animal. This is the *nucleus* (plural *nuclei*). Usually it is very hard to see in a living ameba. What have you learned about cells by looking at the ameba?

*b*) Cut a slice out of a small onion, and select a piece of one of the thick, juicy layers of the onion. With a pair of tweezers peel off a piece of the inner or outer skin of the layer. Spread the piece you get on a glass slide in some water. Put a piece of very thin glass (cover-glass) on top of the water and onion skin.

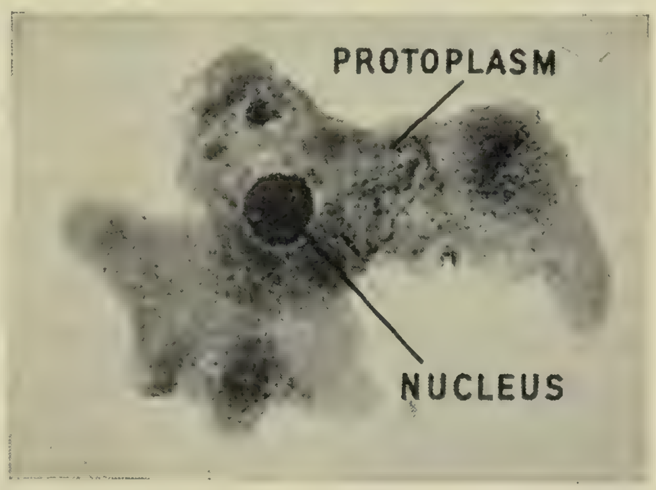


FIG. 86. The ameba, a one-celled animal, has protoplasm and a nucleus. Nearly all living cells have these same parts.

Look at the cells of the onion skin with the low power of the microscope. These cells have prominent walls between them. Make a drawing of a group of six or eight cells to show their shapes and how they fit together.

Look for a small, round, yellowish lump inside each cell. This is the nucleus of the cell. You should see a nucleus in each cell if the cells have not been torn to pieces. Look for the clear protoplasm around the nuclei or in little streaks near the cell walls or across the cells. You will need to look carefully to see it, and you may not see it at all. In your drawing show the nuclei, and also the protoplasm if you were able to see it.

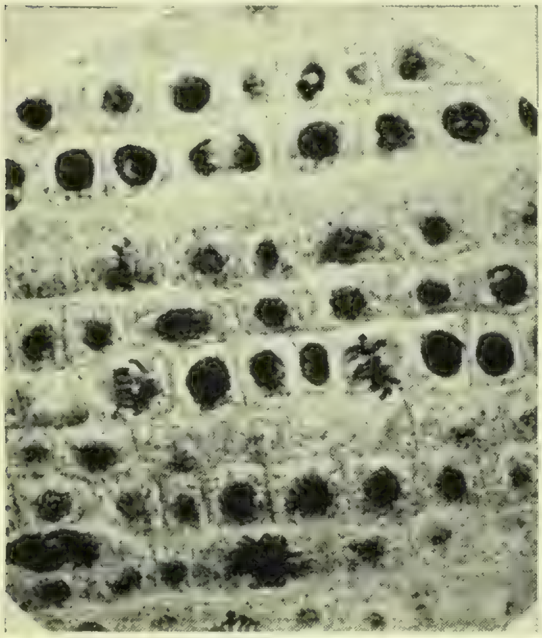

Fig. 87. Cells in the tip of an onion root under the microscope. The dark spots are nuclei.

All living cells have inside them a clear, syrup-like material that is somewhat like white of egg. We call this material *protoplasm*. Each cell has also a rounded, darker piece of protoplasm. This is the *nucleus*. Without its nucleus a cell cannot live long. Practically all living cells have these two kinds of protoplasm, the lighter protoplasm and the darker protoplasm that makes the nucleus. Many cells have a *cell wall* that the protoplasm has made around itself. In wood the cell walls are very thick and strong. These walls make wood so stiff that it can be used for buildings.

However, there are many cells, especially in animals, that make no cell walls around themselves. Even our bones have cells in them. Through chemical change, the bone cells have built the hard calcium phosphate around them to make our stiff, hard bones. You can understand this better if you imagine a building first made of little blocks of jelly which later made hard, strong concrete around themselves. The little cells go on living in the bone. Then, when the bone is broken and needs repairing, or when it is growing larger, the cells are ready to do the work.

Cells have many different shapes and sizes. A large ameba is about 1/100 of an inch across. It is really quite a large cell. The smallest cells we know are *bacteria*. Figure 88 shows one kind. But what would you think of a cell that weighs nearly one pound? The yolk, or yellow part, of an ostrich's egg is a single cell and weighs that much. Part of it is made up of food to help it grow into a young ostrich. Some of the nerve cells in your body have long, slender branches that reach all the way from the lower part of your backbone to your big toe. Think how long the nerve cells of an elephant must be! But most cells of animals are very small—even smaller than the cells of plants.

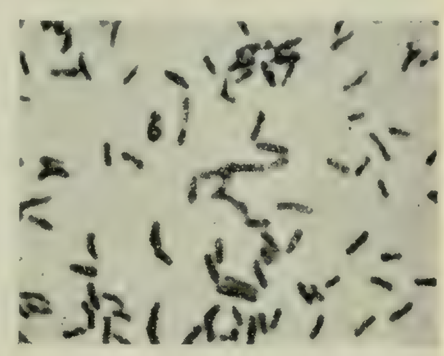

FIG. 88. These tiny one-celled plants, or bacteria, were magnified 2000 times to get this picture. This kind of bacteria lives in the roots of plants and can take nitrogen from the air and change it into nitrogen compounds that the plant needs.

Each large plant or animal has many kinds of cells. Our bodies have long, slender nerve cells to carry messages, muscle cells to help us move, rounded cells to hold stored fat, and flat, thin cells to form a covering for the body. Some of these different kinds of cells are shown in Figure 89. Plant leaves have coverings of flat, thin cells, and they have long, slender cells, like tubes, to carry liquids through their stems and leaves. (See Figures 84 and 87.) Thus you see that each different organ and part of an organ in plants and animals has its own kinds of cells.

You can also understand that each different kind of cell has its own work to do. Each kind of cell is made in its own way; it has its own peculiar shape and is fitted to do its own kind of work. Thus the body of a plant or of an animal is like a community of people. The cells all work together, each kind doing some special work for all the other kinds. If one kind is hurt or dies, the whole community of cells (plant or animal) is disturbed. A community of one million billion (1,000,000,000,-000,000) people, all working together, is hard to imagine. Yet each of us is a community of about that many cells! And most of the time they work together very well. Your brain has about

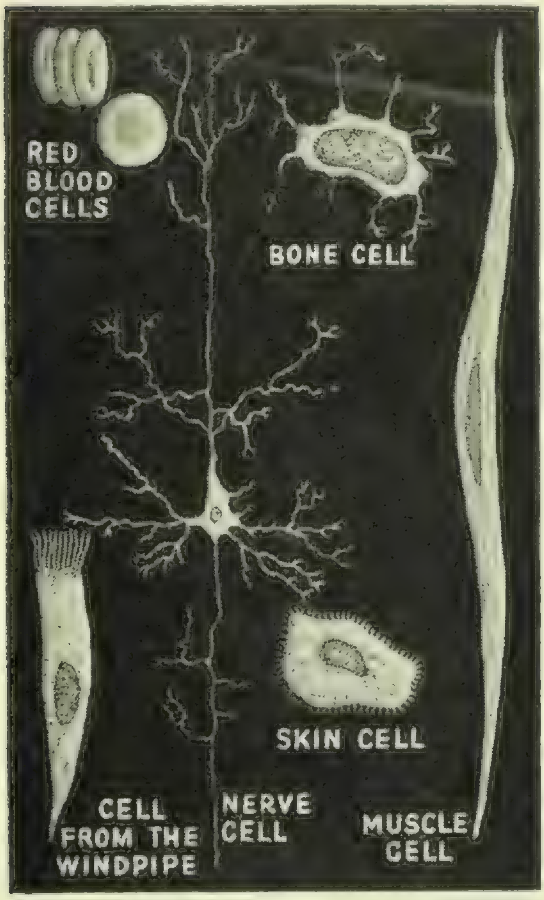


FIG. 89. There are many different kinds of cells in the human body.

two thousand billion cells in it. Your blood contains about fifteen thousand billion cells. Plants are like animals, for they, too, have great numbers of different kinds of cells that work together. Each different kind does its own work.

WHAT DOES THE PROTOPLASM IN CELLS DO? A great scientist once said that a cell is just a bit of protoplasm with a nucleus in it. Of course, cells may have other parts, such as a wall, but the living, active part of the cell is the protoplasm. This protoplasm is a strange mixture of the compounds you learned a little about in Problem 2. No scientist has ever been able to put the right things together in the right way to make protoplasm. So far as we know, the only way we can get protoplasm is to have it made by other living protoplasm.

In Problem 1 you learned that all living things do certain things. Now do you see what this simple-looking, syrupy material called protoplasm can do? It is the only living part of plants and animals. It is really doing all the things that you and plants and other animals do. Protoplasm takes in food. From that food it makes all the chemicals the body needs. From the food it also makes more protoplasm so that we can grow and repair the worn-out and injured parts of our bodies. Protoplasm takes in oxygen and uses it and gives out waste materials. Protoplasm sees and hears and tastes and smells and feels for us. Protoplasm responds to all kinds of stimuli in many ways. All plants and animals are alike in what they do because they all are made of protoplasm. What wonderful stuff protoplasm must be! And yet you have not learned half of its wonders!

*Self-Testing Exercises.* 1. Write a paragraph in which you tell what cells are.

2. What is protoplasm? What can protoplasm do?

3. What can cells do?

4. Tell some of the ways cells are different from each other.

5. How is the body of a plant or an animal like a community of people?

6. Problem 3 tells at least three new ways in which plants and animals are alike. What are these three ways?

*Problems to Solve.* 1. What does an ameba do? How do you know? Find out by reading how it carries on each of these activities.

2. Why do plants and animals need different kinds of cells?

3. What can protoplasm do that chemists cannot do in their laboratories?

4. What elements would you expect to be most plentiful in protoplasm when it is analyzed?

## ¶ 4. Where do all living things get their energy?

WHERE DO ALL ANIMALS GET THEIR FOOD? When scientists began to think carefully about the foods of animals, they discovered a strange fact. Let us see what this strange fact is by first thinking about the kinds of food that animals eat. Some animals, such as horses, elephants, cows, sheep, squirrels, and rabbits, eat only plants or parts of plants. These animals and others that live entirely on plant food are called *herbivorous*, or "herb-eating," animals.

But not all animals are herbivorous. Some kinds live almost entirely on the bodies of other animals. These kinds are said to be *carnivorous*, or "meat-eating," animals. Probably you think first of the cat family or the dog family when we mention meat-eating animals. What do cats eat? Tame cats eat some plant foods, such as bread and cooked vegetables, but they usually prefer animal food, such as beef, pork, mice, rabbits, and birds. Animals that belong to the dog family, such as wolves, foxes, and coyotes, eat about the same kinds of food as the cat family.

Now let us look again at the food of the carnivorous animals. Lions, tigers, and wolves eat deer, rabbits, and other animals.

Fig. 90. Animals use both plants and animals for food. Squirrels live largely on nuts and other seeds of plants. Lions and tigers catch antelope, buffalo, deer, and similar animals.

Some birds eat insects and worms. But the deer, rabbits, insects, and worms live on plants. Have you already guessed the important fact that scientists have discovered about the food of all animals? *All animals get their food directly or indirectly from plants.* At first this statement does not seem to be true, but if you will trace back the food of two or three different kinds of meat-eating animals, you will find that the statement is true.

Let us take the case of a man eating a fish as an example of an interesting "food chain" that leads back to plants. Many large fish eat smaller fish and insects. Most insects eat plants, or they eat other insects that eat plants. Small fish eat small water animals. These small water animals eat still smaller water animals that eat the tiniest kinds of plants. So, in each case, we find that the food of all animals can be traced back to plants.

*Self-Testing Exercises.* 1. (*a*) What is an herbivorous animal? Name three. (*b*) What is a carnivorous animal? Name three.

2. Why do we believe that animals cannot live without plants?

*Problem to Solve.* Observe a horse or a rabbit eating grass. Compare the methods they use with those of the cow. Try to explain just why they use different methods.

Where do green plants get their food? Plants do not move from place to place; they have no eyes and ears, no noses, and no mouths; and they cannot make noises; therefore we often forget that they are just as much alive as we are. Since plants are alive, they need food just as much as animals need food. Without food, plants cannot stay alive and cannot grow. If you ask people the question, "Where do plants get their food?" many of them will answer you in this way: "Plants

get food from the soil through their roots." Now let us see if that is the way a scientist would answer the question.

You know that you cannot eat soil for food. Neither can a horse, a dog, or a cat. Neither can a plant. But you can eat plants, because plants have food in them. Our problem is to discover where the plants get their food.

Potatoes, as you know, are a good source of food. They contain a food known as *starch*. Raisins are also a good source of food. They contain a food that we call *sugar*. You can easily show that potatoes contain starch and that raisins contain sugar. Scientists have worked out chemical tests to show whether materials have starch or sugar in them.

*Experiment* 31. HOW DO WE TEST FOR STARCH AND SUGAR? (*a*) Scrape some of the white part of a potato to get a pulpy mass. Put a drop or two of iodine on it. (See page 40.) What color does it become?

*b*) Grind some raisins and add a little water. Allow the solid materials to settle, and then pour off the liquid into a test-tube. Add a very small amount of Fehling's solution to the liquid, and boil. Any greenish or yellow or red color when you heat the solution shows that there is some sugar in the material you are testing.

Now how does the potato plant get starch and how do raisins (which are a kind of dried grape) get sugar? The roots of potato plants and of grape-vines grow down into the soil, and the leaves grow up in the air. Are there starch and sugar in the soil or in the air? The chemist tells us that he can find neither starch nor sugar in either soil or air. He tells us, however, that he can find in the soil and the air substances which contain the same elements that are in starch and sugar.

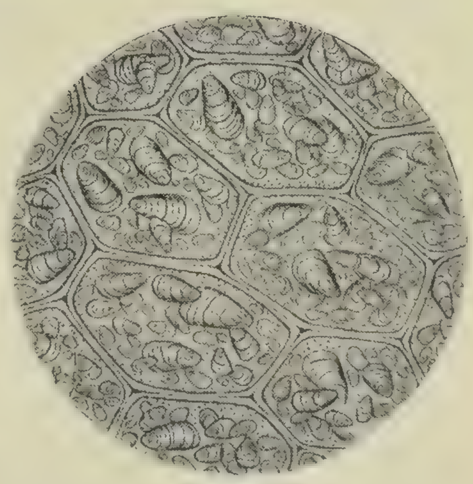

FIG. 91. Potato cells with starch grains in them, as seen with a microscope

These facts seem to tell us that the plant takes substances from the air and soil and manufactures starch and sugar from them. In other words, the plant makes food (starch and sugar) from raw materials that it gets from the soil and air. This

starch and sugar are used by you and by the plant for food. Now you can see why the answer, "Plants get food from the soil through their roots" is not correct. The true answer is that plants get materials from the soil and air, and from these materials they can make food.

*Self-Testing Exercises.* 1. How do we know that plants make starch?
2. What uses must a material have to be called a food?

*Problem to Solve.* Some plants such as Venus's fly-trap, the sundew, and the pitcher-plant use animals for food. Find out how they capture animals.

WHAT RAW MATERIALS DO GREEN PLANTS NEED TO MAKE FOOD? You have learned that plants make sugar and starch. Sugar and starch are two different kinds of compounds, but they are made from the same elements joined together in almost the same way. Starch and sugar are called *carbohydrates*. You will soon see why they are given this name. What do the plants use to make carbohydrates? To answer that question, the first thing to do is to find out what carbohydrates are made of.

*Experiment 32.* WHAT ARE CARBOHYDRATES MADE OF? (*a*) Put a small amount of dry starch in a test-tube. Heat the starch until it turns black. At the same time watch the sides of the test-tube. What do you see on the sides of the test-tube as the starch begins to turn black? Heat the starch until no further changes take place. What is left? (What common element is usually black?)
*b*) Do the experiment again, using sugar.

As you heated the starch and sugar, you probably noticed little drops of liquid on the inside of the test-tube. You cannot be sure what the liquid is, but chemists can prove that it is water. When starch and sugar decompose because of heat, they give off both carbon and water. Now you see that carbohydrates are compounds of carbon and water. *Carbo* is the first part of the word carbon; *hydrate* comes from a Greek word meaning water. So the word "carbohydrate" tells us what materials are found in carbohydrates. You already know that water is a compound composed of hydrogen and oxygen; therefore you have found out what carbohydrates are made of. They are made of three elements—carbon, hydrogen, and oxygen.

To make carbohydrates, plants must have raw materials that

contain the three elements—carbon, hydrogen, and oxygen. You know that water is made of hydrogen and oxygen; therefore, water gives the plant two of the elements it needs. But where does the carbon come from? Air, you know, is a mixture of gases. One of these gases in the air is the compound, carbon dioxide ($CO_2$). From the carbon dioxide in the air the plant gets the third element it needs—carbon. From the water in the soil and from the air around the leaves and stems, the green plant gets the raw materials to make starches and sugars for food.

But starch and sugar are not the only kinds of food that plants make. There are other kinds of food made by green plants, and these other kinds need some different raw materials. Let us see what else the plant needs besides carbon dioxide and water.

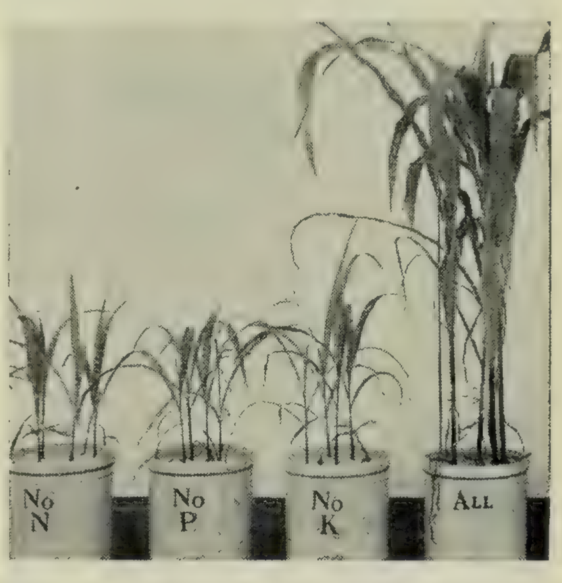

Fig. 92. Experiments show the importance of minerals in the soil. The plant grown in soil containing nitrogen, phosphorus, and potassium grew twice as large as the others, which lacked one of those minerals. (U. S. Bureau of Plant Industry photo)

In Problem 2 you learned that in your body there is about a pound of phosphorus and about enough iron to make a good-sized nail. You also learned that your bones are made largely of calcium. As you know, iron, phosphorus, and calcium are elements. They are found in compounds that are called *minerals*. We get minerals from the food we eat, and all our food comes from green plants. Therefore, green plants must have minerals as well as carbon and water to make food. Where does the plant get these raw materials—the minerals?

*Experiment* 33. DOES SOIL CONTAIN MINERALS THAT WILL DISSOLVE? (a) Fasten a piece of fine wire screen or cheese-cloth over the small end of a lamp chimney. Support the chimney over a clean tumbler (Figure 93). Put about an inch of fine sand into the chimney. On top of the sand put rich, black soil almost to the top of the chimney.

Pour a tumblerful of rain-water or distilled water on top of the soil.

Collect the clear water that seeps through the soil and sand into the tumbler. If the tumbler is not almost full of water, pour some more water on the soil. This water in the tumbler will be like the soil water around plant roots.

*b*) Boil the soil water away or allow it to evaporate from a shallow dish. Is anything left in the dish?

*c*) Evaporate an equal amount of rain-water or distilled water from a clean dish. Is any material left in the dish? Where did the water you evaporated in part *b* get the material it left behind in the dish?

FIG. 93. Apparatus for Experiment 33

The whitish or brownish material left in the dish after the soil water had evaporated was composed of minerals. These minerals dissolved in the water as it soaked through the soil. Dissolved minerals are absolutely necessary to plants in making food and in growing. They are also necessary for animals and for people. We get the minerals we need when we eat plants or when we eat meat, milk, and eggs from animals that eat plants. The plants get the minerals from the soil.

*Self-Testing Exercises.* 1. Why are starch and sugar called carbohydrates?

2. From what compounds do plants get the elements that are in starch and sugar?

3. What are minerals? Where do plants get minerals?

*Problems to Solve.* 1. There are many kinds of fertilizers on the market. Find out what minerals these fertilizers contain.

2. Read the caption for Figure 88, page 149. Then refer to a biology text to find out more about the *nitrogen-fixing* bacteria.

HOW DO PLANTS GET WATER AND MINERALS FROM THE SOIL? The kinds of plants you know best are called seed plants. They have roots, stems, leaves, flowers, and seeds. Roots, stems, and leaves are made in such a way as to help these plants get raw materials and make food. Let us first see what we can learn about the roots of plants.

*Experiment 34.* WHAT ARE ROOT-HAIRS? Place a piece of a blotter or several pieces of towel paper on a piece of window glass about three inches square. Lay several radish seeds or other small seeds on the paper. On top of the seeds lay another piece of glass the same size as the first.

Fasten the squares of glass together with rubber bands. Lay the whole apparatus in water overnight. Then set the apparatus on edge in a pan or dish that contains one-half inch of water. Put the pan in a warm place until the seeds begin to grow.

When the roots are about an inch long, study a single plant and its root through the glass. The white fuzz along the root is composed of tiny *root-hairs* (Figure 94). Where are the root-hairs longest? Where shortest? Are there any at the very end of the root? Make a drawing to show what you have noticed about the root-hairs of your plants.

Put the plants back as they were, and look at them from day to day. Do more root-hairs grow? Where do they grow?

FIG. 94. Root-hairs of sprouting corn and bean seeds

The tiny white root-hairs that you have seen are hollow tubes that grow from the cells on the outside of the root. They are filled with the watery sap of the plant. Root-hairs grow on only one part of a root, the part within an inch or so of the end. They grow very close to the tiny pieces of soil. There are so many of them and their walls are so thin that they are able to take in all the water and minerals a plant uses.

In many plants the root system is larger than the part of the plant above the ground. A corn plant, for example, may have fifteen or twenty main roots. From these main roots there may be several thousand smaller roots reaching out through as much as 200 cubic feet of soil. The larger roots and even the smaller

roots have a thick covering that keeps them from taking in much water. Thus, in order to take in water, each plant has millions of root-hairs such as you saw on the roots of the little radish plants in Experiment 34. When a plant is dug up, many of the root-hairs break off and remain in the soil.

You can see now why it is hard to move a plant to a new place. No matter how careful you are, many small roots and root-hairs are broken off. The plant cannot take in much water until it grows new root-hairs. When a gardener moves a plant, he often cuts off some of the branches and leaves. He does this because water evaporates from the leaves. With fewer leaves, more water will stay in the plant until new root-hairs can grow and take in water from the soil.

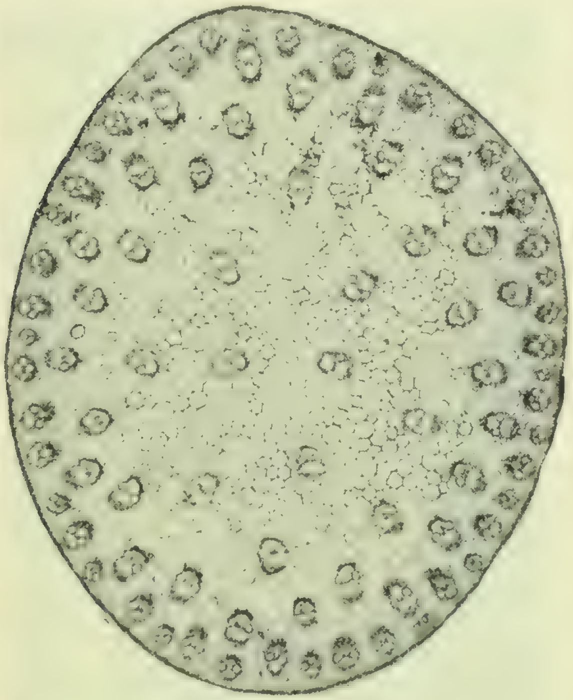

FIG. 95. A thin slice of corn stem, magnified to show the scattered bundles of tube-like cells that carry food and water

HOW DO WATER AND MINERALS REACH THE LEAVES? Big factories must have some way of carrying raw materials from one part of the factory to other parts. Trucks and railroad cars bring the materials to the doors. Derricks, cranes, and trucks carry the materials to the machines and furnaces that make things. The green plant, too, must have a way of carrying raw materials all through it.

When the water and minerals get into the roots, they must travel on up through the plant. They must get up to the leaves, because the green leaves are the food factories. The raw materials that the plant uses to make food—carbon dioxide, water, and minerals—must get into the leaves.

*Experiment* 35. WHERE ARE THE WATER-CARRYING TUBES OF PLANTS? (a) Put the stem of a freshly picked daffodil or a white carnation into some water that is well colored with red ink. Cut the lower ends off

a piece of celery and a small corn plant and put these in colored water, too. Leave these plants in the liquid for about two hours. Into the inky water put also the leafy twig of a maple tree, and leave it for a day or more.

Can you see where ink has passed into the flower or leaves? Hold the leaves up to the light and compare their color with that of untreated leaves. Can you see little *veins* that have turned pink? Cut across the stems of the plants. Can you see where the ink colored the stems red? With tweezers or any sharp instrument pick the stems to pieces and follow the red streaks up through the stems to the leaves.

*b*) With a pair of tweezers remove the soft, white material carefully from a dry cornstalk. Leave the tough threads unharmed. See how the threads are arranged.

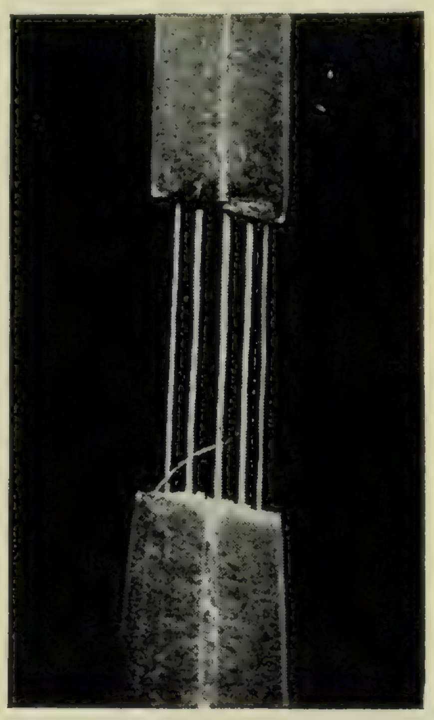

FIG. 96. In the celery stalk the vascular bundles are arranged in a circle.

You can understand better what you saw in the experiment if you look at the cut end of a stem under a microscope. Figure 95 shows how one kind of stem looks. Do you see some round bundles of cells? These are called *vascular bundles*. Some of the cells in each bundle are so tough and hard that the bundles are strong (Figure 96). In one part of each bundle the cells are hollow tubes joined together, so that the water can pass rapidly through them up to the leaves. In Experiment 35 the red ink went up through these tubes in the vascular bundles.

The tubes that carry water upward in trees are in the wood just underneath the bark. The cells that carry food downward from the leaves are in the part of the bark that is next to the wood. Do you see that a tree has two sets of special cells in its *circulation system?* One set carries water and minerals from the roots to the leaves; the second set carries materials from the leaves down to the stem and roots.

Look carefully at a green leaf. You will see that it has *veins* all through it. In the leaves of some plants, like maple trees,

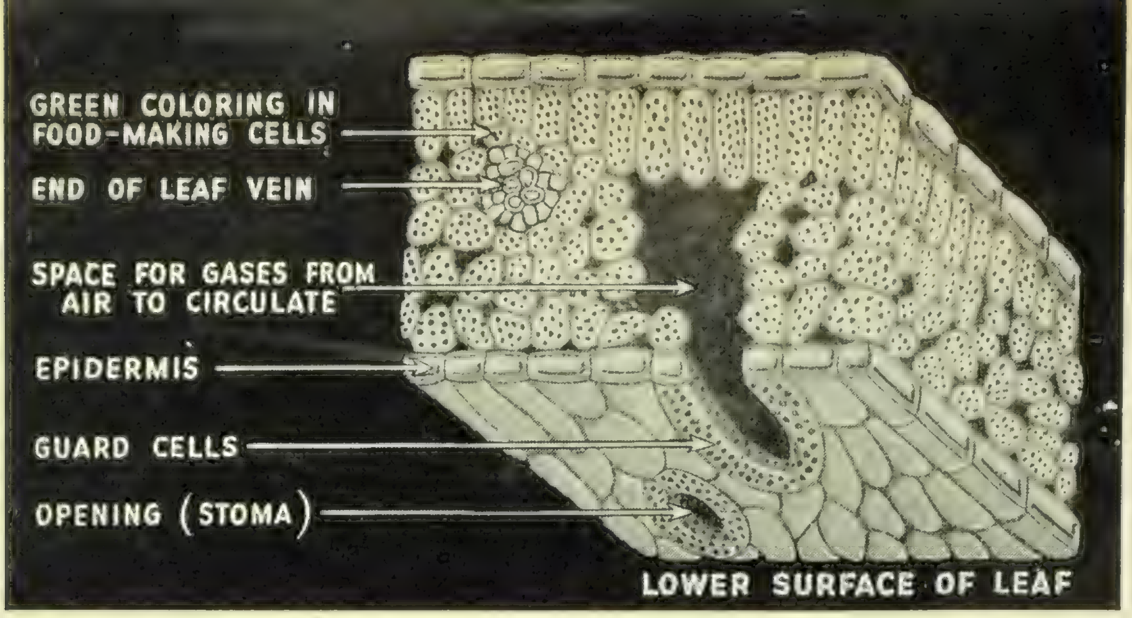


FIG. 97. This drawing shows how the cut edge of a leaf would look if it were enlarged several hundred times.

beans, and geraniums, these veins form a network. In grass leaves and corn leaves the veins run parallel to each other. Often you can see the veins more clearly by holding the leaves up to the light. These veins are really the vascular bundles of the leaves. In Experiment 35 you probably noticed that the red streaks ran right up through the stems into the leaves. Every part of a leaf is very close to a vein. Thus every cell of a leaf is very close to a "water pipe." The veins also form a framework to help hold the leaf out in the sunlight.

*Self-Testing Exercises.* 1. Tell the story of a particle of water that travelled all the way from the soil to a leaf.

2. Tell the story of a sugar particle made in a leaf as it travelled all the way from the leaf down to a root to help the root grow.

*Problems to Solve.* 1. Why does a plant usually die when the stem is broken?

2. Farmers sometimes kill trees by "girdling" them. To girdle a tree the farmer cuts out a rather deep ring all around the trunk of the tree. Why does the tree die?

3. Of what use to a celery plant are the "strings" you get between your teeth when you eat tough celery?

HOW DOES CARBON DIOXIDE GET INTO A LEAF? You have now learned how the raw materials from the soil get into the plant and up to the leaf factory. But the leaf factory must also have carbon dioxide to supply the carbon in the carbohydrates they make. This carbon dioxide, as you know, comes from the air that is all around a plant. Let us see how a leaf is constructed to let the carbon dioxide pass into the food-making cells.

Look carefully at Figure 97. You can see the end of a vein that brings water to the leaf and carries food away. All around the outside of the leaf is a layer of clear cells called the *epidermis*. Light can shine right through the cells of the epidermis into the inside of the leaf. On the outside of the epidermis is a layer of a waxy material that is waterproof. This layer of material helps keep too much water from evaporating from the cells of the epidermis.

Next look at the part of the leaf between the upper and lower epidermis. The cells in this part have many little green bodies in them. These green bodies make the leaf look green. The cells with the green bodies are the ones that make the food. There are air spaces around most of these food-making cells. And do you see, in the lower epidermis, the little openings that lead from the air spaces out into the atmosphere? Let us examine a leaf with a microscope and see these little openings.

*Experiment 36.* WHAT DOES THE EPIDERMIS OF A LEAF LOOK LIKE THROUGH A MICROSCOPE? Your teacher will show you, through a microscope, the epidermis that has been peeled off some common leaf, like that of a geranium or an onion. Look at it carefully and also study carefully what is shown in Figures 97 and 98.

In most leaves the colorless cells of the epidermis are of irregular shapes. Can you see them? In some places there are pairs of tiny bean-shaped cells. Between each pair of these cells is an opening through the epidermis. Look at the pair of cells and the opening between them in Figures 97 and 98.

FIG. 98. Epidermis of a geranium leaf, as seen through a microscope. Six stomata are shown. (Hugh Spencer photo)

The pairs of cells are called *guard cells*. The little opening between each pair of guard cells in the epidermis is called a *stoma*. (The plural is *stomata*.) "Stoma" is the Greek word for mouth. Notice that each opening in Figures 97 and 98 is shaped like a little mouth. The carbon dioxide from the air enters the leaf through these little mouths.

*Self-Testing Exercise.* Close your book and see if you can make a diagram of the structure of a leaf. Show the epidermis on top and bottom, a vein, some stomata, guard cells, and food-making cells. Put in some arrows to show where the carbon dioxide enters the leaf. Label each part of the leaf.

HOW DO GREEN LEAVES MAKE FOOD? In the leaf we now have the raw materials that the plant needs to make food—water and minerals from the soil, and carbon dioxide from the air. What happens next? By what magic can the plant put carbon dioxide, water, and minerals together to make apples, melons, and nuts—to say nothing of the roots, stems, and leaves of the plant itself? Everything in the plant is made from water, carbon dioxide, and minerals. No one understands exactly how leaves manufacture food. Scientists know that leaves are able to make carbohydrates out of water and carbon dioxide. But just how the leaves do this the scientists do not know. You can, however, learn something about what happens.

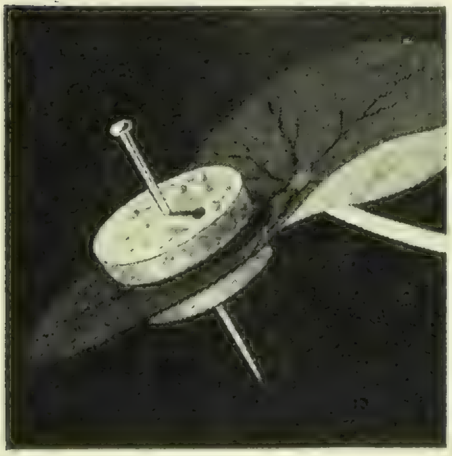

FIG. 99. Experiment 37

*Experiment 37.* DO LEAVES NEED LIGHT IN ORDER TO MAKE STARCH? Obtain a healthy nasturtium or geranium plant. Place it in the dark for at least two days. Then pin two thin pieces of cork or black paper on the two sides of a leaf as shown in Figure 99. (Fix two or three leaves this way.) If the leaf is too heavy to hold itself up, prop it up. Set the plant in bright sunlight for several hours. Then break off the leaf, and dip it in boiling water for a short time. The heat kills the leaf and makes the rest of the experiment work better.

Next put the leaf into alcohol to soak the green color out of the leaf. Set the vessel of alcohol in a larger vessel of boiling water until the green color is gone from the leaf. You may need to get fresh alcohol to get the color all out. Now soak the leaf in a weak solution of iodine. Then spread it out on a piece of glass or cardboard.

Does part of the leaf turn bluish or black instead of brown? Which part changes color? What substance does this show is in the leaf? (See page 40 if you have forgotten.)

Many experiments somewhat like the one you have done show that leaves make sugar and starch only when they are in the light. If green plants are kept in darkness for a long time, they will die. They die because they can no longer make food. Other experiments show that the green coloring in leaves helps make food. Figure 97 shows that the green material is in little green bodies that are scattered through the central part of the leaf. They make the entire leaf appear green. This green material is called *chlorophyll.* Plants must have light in order for chlorophyll to form in the green bodies. Plants that do not have chlorophyll cannot make carbohydrates. Many experiments have been done by scientists to prove that this is true.

You see now that four conditions are necessary before a plant can manufacture food: (1) The plant must have a supply of water. (2) The plant must have a supply of carbon dioxide. (3) The plant must be green (contain chlorophyll). (4) The plant must be in the light.

Now let us get a clearer picture of what happens in a green leaf in the sunlight. The green leaf is a factory. It makes a product (food) from raw materials (carbon dioxide and water). In other words, the green leaf makes a chemical change take place in the raw materials. By this change the raw materials are made into a new material. The change is brought about by the protoplasm and the chlorophyll. Light must shine on the chlorophyll or the change will not take place. The chlorophyll is the machinery of the factory. The protoplasm inside the cells of the leaf manages and takes care of the factory and its machinery. Sunlight furnishes the energy to run the machinery.

No one knows just how chlorophyll and protoplasm make sugar. We do know that the carbon dioxide and the water are changed to sugar, and we know that this change takes place only when light energy shines on the leaf. Scientists call this particular chemical change *photosynthesis* (*photo* means "light"; *synthesis* means "putting together").

Perhaps you are wondering why sugar is a food, while the raw materials from which it is made are not foods. The answer is that sugar contains energy that the plant can use, while carbon dioxide and water do not contain energy that plants can use. Now let us

see why this is true. As you know, the light from the sun is a kind of energy. Part of this energy is absorbed by the chlorophyll, and it is then stored in the molecules of sugar in the form of chemical energy. (See page 105.) Both plants and animals can get this energy from the sugar by oxidizing the sugar. You can see, however, that the energy which plants and animals get from food really comes from the radiant energy given out by the sun. The sun is the real source of all of our energy.

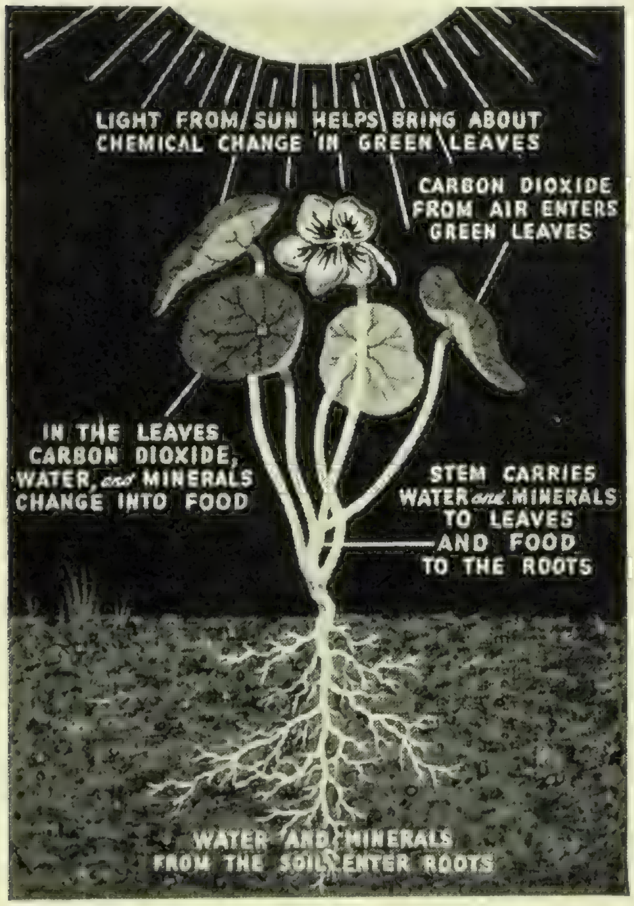

FIG. 100. The food-making factory of the green plant and its source of energy

When we want large amounts of carbohydrates, we look for them in the places where plants have stored them. We dig up the roots of sweet potatoes and beets and the underground stems of white potatoes. We gather the seeds of corn, rice, and wheat. To get sugar, we evaporate the sap of sugar cane, sugar beets, and maple trees. From these and other plants come all the carbohydrates we eat.

But not all kinds of food are carbohydrates. Other kinds are called *fats* and *proteins*. Plants change carbohydrates into fats and store them in such seeds as peanuts, olives, cotton seed, and pecans. Plants also make proteins out of carbohydrates and minerals. Scientists do not know just how the plant is able to change carbohydrates into fats and proteins.

*Self-Testing Exercises.* 1. What materials are needed by plants to make carbohydrates?

2. What material must be in the leaf to make it possible for the plant to carry on photosynthesis?

3. How do we know that light is necessary for photosynthesis?

4. Why can only green plants make carbohydrates?
5. How do you know that photosynthesis is a chemical change?

*Problems to Solve.* 1. Use iodine to test a number of vegetables and fruits to see if they have starch in them.

2. Use Fehling's solution to test fruits and other foods for sugar.

3. Grow two pots of plants from seeds. Keep one pot in a dark place and the other in the sunlight. In which plant can you see more chlorophyll? What do you think this experiment shows about chlorophyll in leaves?

4. Some plants have leaves that are spotted. Parts of the leaf are green, and other parts are nearly white. If these leaves were tested for starch, where would you expect to find it? Why?

HOW DO PLANTS THAT ARE NOT GREEN GET FOOD? You have learned that plants must have chlorophyll to make food, but you probably know, if you think a moment, that many plants do not have chlorophyll. You have seen or heard of bread mold, yeast, mushrooms, and mildew. These are all plants that cannot make their own food. They get food, as animals do, from other living things or from dead things. Such plants are called *dependent plants* because they depend on other things for food.

*Experiment 38.* HOW DOES BREAD MOLD GET FOOD? Put a piece of wet blotting-paper in the bottom of a dish with a tight cover. Place a fresh slice of bread on the paper. Shake some dust from a dust cloth on the bread. Cover the dish tightly and set it in a warm place.

Look at the bread each day. Soon you should see a white, cottony material growing over the surface of the bread. After a time many black specks will appear on the white mass. These specks are tiny balls filled with particles that will grow into new bread mold plants. Fuzzy patches of green or yellow material that may appear on the bread are other mold plants that commonly grow on bread or fruits.

Bread, as you know, is made from flour, and flour is made of wheat, which grows on green plants. The bread mold sends tiny thread-like tubes, called *hyphae*, into the bread (Figure 101). These hyphae give out chemicals that cause chemical changes in the bread and cause some of it to dissolve. The dissolved food then passes into the hyphae, much as the water and minerals get into the root-hairs of green plants. When the food gets inside, it is used by the mold for growth.

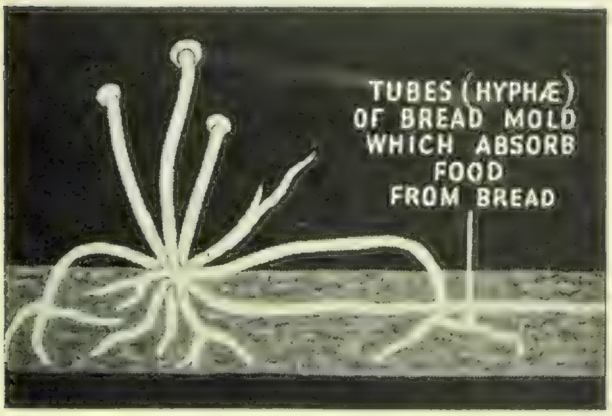


FIG. 101. This drawing shows how tiny thread-like parts of bread mold, called hyphae, grow and work their way into the bread to absorb food for the mold plant.

FIG. 102. Bread mold under the microscope. The black balls are full of tiny particles that will grow into new plants. (Hugh Spencer photo)

There are thousands of kinds of plants that are not green. They grow on damp bread and crackers, old leather, damp clothes, meat, milk, fence posts, old logs, and dead leaves. In fact, they grow on almost anything that has ever been alive or that has come from living things. All those plants that get their food from things that are not alive are called *saprophytes.* In addition to saprophytes there are *parasites*, that is, plants that live on or in the bodies of other living things and get their food from them. For example, bacteria living in the bodies of animals are parasites. So are the mold-like plants that live on the leaves, stems, and fruits of green plants. Plants which have no chlorophyll must get food that has already been manufactured by a green plant.

*Self-Testing Exercises.* 1. What is the reason why mushrooms and molds cannot make their own food?

2. How does a mold get food?

3. How are the hyphae of molds like the root-hairs of green plants, and how are they different?

4. What is the difference between saphrophytes and parasites?

5. How are animals and dependent plants alike?

*Problems to Solve.* 1. See how many different kinds of mold you can get to grow on bread or find growing on decaying fruit, etc.

2. Find as many non-green plants as you can at home and in the woods. Learn their names if you can.

3. Tell of some damage that dependent plants have done to you or to things that belong to you.

4. Just after periods of damp, warm weather look for mushrooms. Find the white, mold-like hyphae that get food for the mushrooms. What do the mushrooms use for food?

5. How do bacteria and molds live when they cannot get any more food? You can find information on this in biology or botany books or in an encyclopaedia.

## Looking Back at Unit 5

1. Use from one to one and a half pages of large note-book paper to write the answers to the following questions. Answer each question in one paragraph.

a) How are plants and animals alike in what they do?
b) How are plants and animals alike in the compounds and elements they contain?
c) How are plants and animals alike in the way they are put together?

2. Write a one-page answer to the problem, "Where do all living things get their food?"

3. Show that you know what the following words mean:

| | | | |
|---|---|---|---|
| *protoplasm* | *vascular bundle* | *cell* | *stoma* |
| *carbohydrates* | *epidermis* | *nucleus* | *stimulus* |
| *carnivorous* | *herbivorous* | *photosynthesis* | *hyphae* |
| *chlorophyll* | *parasite* | *saprophyte* | *vein* |

## Additional Exercises

1. A queer-looking plant called a *fungus* is growing on the side of a dead tree. Do you think it gets food to live? If so, where do you think it gets food?

2. Put a fertile egg under a "setting" hen or into an incubator kept at 103 degrees Fahrenheit. Put a bean between pieces of moist blotting-paper. Keep the paper moist. At the end of five days break the egg into a saucer of warm salt water and compare it with the bean. What has happened to both of them? How are the things that have happened to both of them alike?

3. Get a potted plant. Wrap the pot in waxed paper so that water cannot evaporate from the pot and soil. Fasten the paper around the stem of the plant, leaving only the stem and leaves sticking out. Put a large glass jar over the plant and leave it for

several hours. Be sure that the jar is clean and dry before you use it. What do you find on the inside of the glass? Where did this come from?

4. All living things respond to such stimuli as light, heat, chemicals, and water. Which make more different kinds of responses, plants or animals? Can you find out why?

5. Read in books about the kinds of plants that have no seeds—algae, fungi, mosses, ferns, etc. Then see how many of these kinds of plants you can find for yourself.

6. If certain green water-plants are placed in an aquarium with certain small water animals and then the aquarium is sealed, both plants and animals will go on living without the addition of new food or oxygen. Explain how this is possible.

7. There is much less sap in plants in winter than in the spring. State a reason that will explain this.

8. The color of the grass under a board is different from the grass around it. Find a board lying on the grass and examine the grass to see how it is different. Explain what you see.

9. Newly picked peas and sweet corn are sweeter than after they have been kept for a day. Explain.

10. Look at different kinds of green plants in your home, in greenhouses, or outdoors to see how they place their leaves to catch sunlight. Look at tall plants, vines, and plants that grow close to the ground.

## Books to Read

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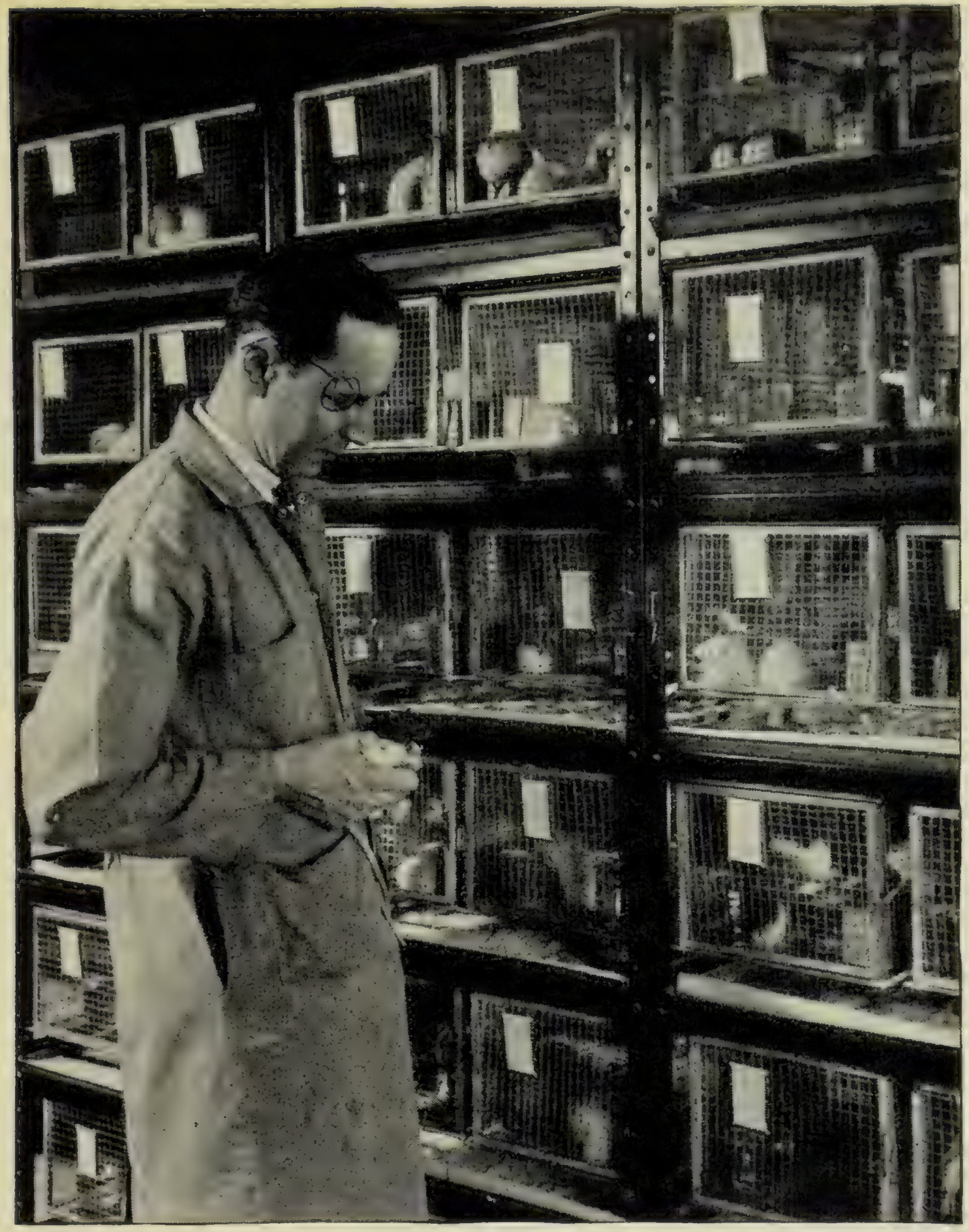

SOME OF THE most important discoveries about what foods do for us have been made by experimenting with the food of animals. From the ways different kinds of food affect animals, scientists can usually tell how these foods will affect men and women and boys and girls. This picture shows a scientist with his white rats and guinea pigs that are being used to make discoveries about food. (Du Pont photo)

# UNIT 6

# How Does Your Body Use Food?

## Looking Ahead to Unit 6

Sometimes stories are written that tell how we shall live a few hundred years from now. Often in these stories we are told that eating will be simply a matter of swallowing pills. The stories predict that scientists will discover how to concentrate foods until a single pill will give us as much nourishment as a whole dinner. Now it is true that soldiers and explorers today carry concentrated foods, but they are not pills. Pills probably will not take the place of food during your lifetime. Even if the scientists could make food pills that would meet all the needs of our bodies, we would not be very well satisfied with them. No food pill could ever take the place of roast turkey, cranberry jelly, mince pie, and ice-cream.

Eating would be still more enjoyable if we could always eat the things we like best and as much of them as we want. A dinner of ice-cream, strawberry shortcake, cherry pie, and chocolate cake would be very pleasant. But it would not be pleasant an hour or so later when pains began to shoot through your stomach. Even if you could eat this mixture of desserts at every meal without getting a stomach-ache, such a diet would not help you grow strong and do all of the things you want to do every day.

All of your life someone has probably told you what you should eat. "Eat some more bread and butter." "Drink your glass of milk." "Don't forget your carrots." You have probably heard such remarks many times. Sometimes you rebelled. You did not see why you should eat carrots, when what you really wanted was a big piece of pie. But your parents had good reasons for asking you to eat different kinds of food. They knew that your body needs a well-balanced variety of food in order to carry on all of its activities. It needs certain kinds of food to help


The Hoggled Contest

FIG. 103. At an annual convention of the 4-H Clubs of America these young people were chosen as the healthiest of the 2,000,000 members of these splendid organizations. Understanding the different kinds of foods and obeying the rules of good eating helped them to become health champions. (Acme photo)

it make new cells and to grow. It needs other kinds of food to keep itself warm and to help it move about. It needs still other foods to make the various important chemicals in the body. Because these important activities are going on all the time, your parents know, too, that it is important to form the habit of eating the right things regularly. Your body will not stay healthy if you eat correctly only occasionally and eat just what you want the rest of the time.

Now you are old enough so that no one should need to tell you what to eat. You should know what to eat. And what is more, you should know why you need to eat certain kinds of food. When you select a meal at the school cafeteria, you should choose the right assortment of food. Perhaps you do this now without really knowing why. It is much more interesting, however, to select your food when you know how to do it scientifically. In this unit you will learn what your body does with food, the different kinds of food your body needs, and how to select the foods that will keep you healthy.

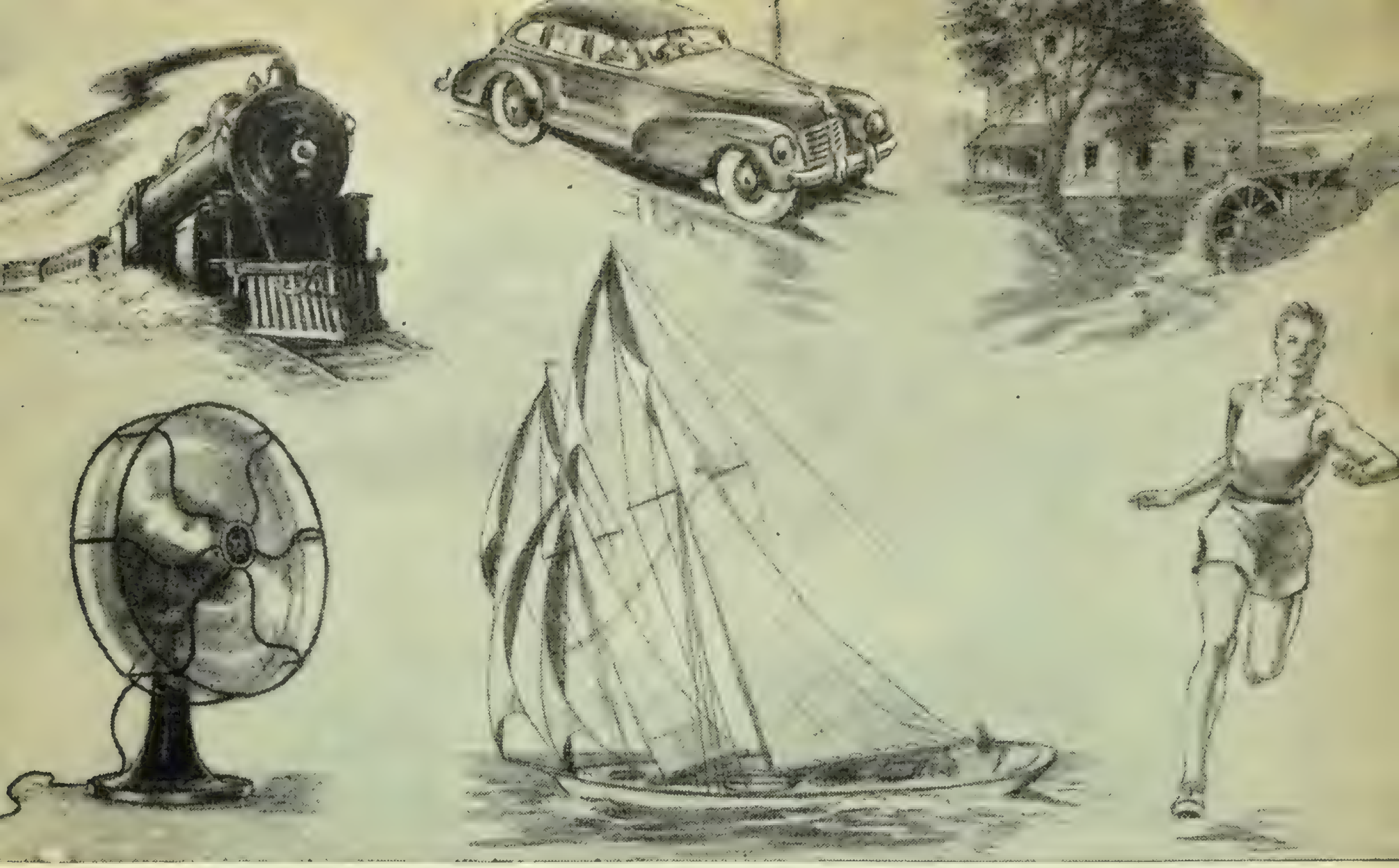

FIG. 104. Nothing moves without the use of some kind of energy. From what does the energy come that moves each of the objects in this picture?

## 1. Why does your body need food?

IF SOMEONE ASKED YOU to describe how you feel when you are hungry, what would you say? You know when you are hungry, but to tell how you know is very difficult. Did you ever wonder why you get hungry? The feeling of hunger is the signal that your body gives you to let you know that it needs more food. This brings us to another question, namely, "Why does your body need food?"

You already know one answer to this question. Every time you move your legs, arms, eyes, and fingers, energy must be used. Movement is also going on inside your body when your heart beats and inner parts of your body move. You also know that your body stays at a temperature of about 98.6° F. if you are well. Heat is one kind of energy, and nothing can move without energy. Your body needs energy for movement and for keeping itself warm. The source of all this energy is the food you eat.

You know, too, that the work of your body is done by the billions of cells that make up your body; therefore it is the cells that need energy to carry on their work. In Unit 5 you learned that green plants store chemical energy in the food they manu-

facture. In Unit 4 you learned that the chemical energy stored in materials can be changed to heat energy when the material combines with oxygen. In your body food and oxygen are carried to the cells by the blood. The food is oxidized by the oxygen, and the chemical energy of the food is changed into the kinds of energy that your cells and therefore your body can use. Much of the useful energy is heat and motion. Without food your body could not carry on its activities, for these activities require a constant stream of energy.

If you look at a picture of yourself when you were a baby, you wonder how you could ever have been so small. When you were born, you probably weighed less than ten pounds and were less than two feet in length. How has your body been able to grow? What has taken place inside your body to make this change? In Unit 5 you learned that the living protoplasm in cells can make new protoplasm. Cells grow larger, and new cells are made. This is what happens when you grow. But the cells must have materials to make new protoplasm. These materials are obtained from the food you eat. In the cells, meat, milk, potatoes, and other foods are made into bone, muscle, hair, and other parts of your body. Now you know another purpose for which the body uses food.

Were you ever unfortunate enough to have a broken arm or leg? How was it repaired? When you break a part on your bicycle, you can replace it with a new part. But you cannot buy arms and legs like the ones you have. You call a doctor, and he puts the ends of the broken bones together; then he places them in a cast. The cells in the bones then go to work. They use food to make new protoplasm and cells, and the bone finally grows together.

Worn-out parts of the body are also repaired by the cells from materials they get in the food. Every time you wink your eye, sit down, get up, think, look, listen, or move any part of the body, certain parts of cells and food materials in them are oxidized and destroyed. These must be replaced by the same kinds of materials that the cells are made of. The only place your body can get these materials is from the food you eat. The living protoplasm in the cells can take these lifeless materials that you

FIG. 105. If you eat at the school cafeteria, do you select your foods wisely or do you just "load up" with the things you like best? What you like to eat and what your body needs may be two quite different things.

eat and change them into new protoplasm. In this way self-repair takes place in the body of every living thing.

Your body also needs food from which to manufacture compounds that are needed by your body. For example, you have certain chemicals in your stomach and intestines that change your food so that your body can use it. These chemicals are not found in the food you eat. The cells can, however, change some of your food into these chemicals. Other chemicals are needed to regulate how fast you grow, how fast your heart beats, how rapidly your food oxidizes, and how your muscles work. These chemicals are compounds that are made by your cells from the elements and compounds in the different kinds of food you eat.

You will now understand that the cells of your body use food for four purposes: (1) They oxidize food to get the energy they use to do things and the heat to keep you warm. (2) They use food to build new body material as you grow—new protoplasm, new bone, new muscle, new nerve material. (3) They use food to repair the worn-out and injured parts of your body. (4) They get from food, or make from it, all the chemicals needed in the body. Anything that is used by the body for one or more of these four purposes is usually called a food.

*Self-Testing Exercises.* 1. With your book closed, write down the four uses of food in the body.

2. Explain how your body gets the energy it needs.
3. Where does oxidation take place in your body?
4. How is the body kept in repair?

FIG. 106. Honey, bread, sugar, navy beans, macaroni, oatmeal, and potatoes contain much carbohydrates. These foods give the body warmth and energy. (J. C. Allen-Century photo)

*Problems to Solve.* 1. Compare your body with a steam engine in the way your body gets its energy and the purposes for which it uses energy.

2. Does oxidation go on all the time or only part of the time? How do you know?

3. How does your body use energy while you are asleep?

4. What is the main use of food by a man digging a ditch?

5. Show the changes that take place in energy from the time it leaves the sun until it keeps your body warm. Use some of the ideas that you got from Unit 5.

6. What kind of energy is moving each object in Figure 104?

## ¶ 2. What kinds of foods meet the different needs of the body?

IN UNIT 5 YOU LEARNED how plants make starch and sugar, and you learned that these food substances are called carbohydrates. Long ago chemists found four other kinds of substances that we all need in our food. These are *fats*, *proteins*, *minerals*, and *water*. Scientists then thought that if anyone got enough of each of these five kinds of substances, he would have all the kinds of food needed to keep him healthy. Later, scientists discovered that we also need tiny amounts of other compounds, called *vitamins*. The discovery of vitamins has been of tremendous importance, as you will learn later in this unit. Why do our bodies need each of these six different kinds of food materials?

OF WHAT USE ARE CARBOHYDRATES AND FATS? Carbohydrates, as you know, are food materials containing three elements —carbon, hydrogen, and oxygen. Starch is a carbohydrate, and so is sugar. Table 10, on this page, gives the percentage of carbohydrates and fats in some common foods. Carbohydrates and

TABLE 10. AVERAGE PERCENTAGE COMPOSITION OF COMMON FOOD PRODUCTS*

| FOOD PRODUCTS | WATER | PROTEIN | FAT | CARBOHYDRATES | MINERALS | FUEL VALUE PER POUND† |
|---|---|---|---|---|---|---|
| Beef, sirloin steak | 54.0 | 16.5 | 16.1 | | .8 | 1100 |
| Beef, round | 60.7 | 19.0 | 12.8 | | 1.0 | 890 |
| Veal, leg | 60.1 | 15.5 | 7.9 | | .9 | 625 |
| Pork, loin | 41.8 | 13.4 | 24.2 | | .8 | 1245 |
| Ham, smoked | 34.8 | 14.2 | 33.4 | | 4.2 | 1635 |
| Chicken, broilers | 43.7 | 12.8 | 1.4 | | .7 | 305 |
| Fish, perch | 50.7 | 12.8 | .7 | | .9 | 275 |
| Eggs, hen | 65.5 | 13.1 | 9.3 | | .9 | 635 |
| Butter | 11.0 | 1.0 | 85.0 | | 3.0 | 3410 |
| Milk, whole | 87.0 | 3.3 | 4.0 | 5.0 | .7 | 310 |
| Cheese, cream | 34.2 | 25.9 | 33.7 | 2.4 | 3.8 | 1885 |
| Bread, white | 35.3 | 9.2 | 1.3 | 53.1 | 1.1 | 1200 |
| Crackers, soda | 5.9 | 9.8 | 9.1 | 73.1 | 2.1 | 1875 |
| Beans, string | 83.0 | 2.1 | .3 | 6.9 | .7 | 170 |
| Beans, dried | 12.6 | 22.5 | 1.8 | 59.6 | 3.5 | 1520 |
| Cabbage | 77.7 | 1.4 | .2 | 4.8 | .9 | 115 |
| Peas, canned | 85.3 | 3.6 | .2 | 9.8 | 1.1 | 235 |
| Tomatoes | 94.3 | .9 | .4 | 3.9 | .5 | 100 |
| Potatoes | 62.6 | 1.8 | .1 | 14.7 | .8 | 295 |
| Apples | 63.3 | .3 | .3 | 10.8 | .3 | 190 |
| Bananas | 48.9 | .8 | .4 | 14.3 | .6 | 260 |
| Oranges | 63.4 | .6 | .1 | 8.5 | .4 | 150 |
| Dates, dried | 13.8 | 1.9 | 2.5 | 70.6 | 1.2 | 1275 |
| Raisins | 13.1 | 2.3 | 3.0 | 68.5 | 3.1 | 1265 |
| Peanuts | 6.9 | 19.5 | 29.1 | 18.5 | 1.5 | 1775 |
| Chocolate | 5.9 | 12.9 | 48.7 | 30.3 | 2.2 | 2625 |

†The fuel value is given in *calories*. See page 187 for an explanation of calories.

fats are *fuel foods* for the body. When they are digested and carried to the cells by the blood, they unite with oxygen, and the energy stored in them is changed into heat energy and into the energy needed by the muscle cells to make the body move.

Since we cannot eat all of the time, it is necessary to store some

* E. V. McCollum and Nina Simmonds, *Food, Nutrition, and Health*. Published by the authors.


FIG. 107. These are some foods that contain much fat. Fats give us more energy than any other kind of food. (J. C. Allen-Century photo)

of the food for future use. After a meal that contains much carbohydrates, the cells of the liver take much sugar from the blood and store it. This sugar is then given back to the blood to take to the cells when the cells need more food for energy. Our muscles always contain some stored carbohydrates, ready to release energy when we need to move quickly. Scientists think our cells can change carbohydrates to fat, too. Fat is also stored away for use when needed. Fats are the most concentrated energy foods. When the cells oxidize an ounce of fat, they get more than twice as much energy as when they oxidize an ounce of sugar.

As you know, all greasy and oily foods contain fats. A fat that is liquid at ordinary temperatures is called an oil. Cotton-seed oil, corn oil, and cod-liver oil are liquid fats that can be digested and used by the body. Butter and lard are foods that are almost pure fats. Fat meat, egg yolk, nuts, cream, and cheese all contain large amounts of fat. (See Table 10.) Plants store most of their extra food in the form of carbohydrates, but animals store much of theirs in the form of fats. Carbohydrates and fats are both known as *energy foods*. They are the foods that give us energy to move and heat energy for warmth. But we must eat something else besides starches, sugars, and fats. We must have foods to repair and build up the body and foods to give the chemicals that are needed to regulate the body.

WHAT DO OUR CELLS USE PROTEINS FOR? Proteins are foods that always contain the element nitrogen in addition to the carbon, hydrogen, and oxygen found in carbohydrates and fats.

FIG. 108. Chicken, milk, cheese, steak, eggs, fish, navy beans, and liver are good protein foods. These kinds of foods provide "building materials" for the body. (J. C. Allen-Century photo)

Some proteins also contain sulphur and phosphorus. We get much of our proteins from such foods as eggs, lean meat, fish, cheese, and milk. Look at Table 10, page 176, and find a number of other foods that give us plenty of proteins.

Our bodies can oxidize proteins to get energy, but proteins have a much more important use. Protoplasm, the living material of our bodies, is made almost entirely of protein and water. Muscle (lean meat), for example, is about one-sixth protein. Our cells cannot make proteins from carbohydrates and fats. Therefore, they must get proteins from food to make protoplasm for new cells and to repair old cells. Proteins are absolutely necessary to provide building materials for our bodies.

OF WHAT USE IS WATER IN THE BODY? Our bodies cannot oxidize water to get energy. Because water cannot be oxidized to get energy, some people think that it should not be called a food. Just the same, every one must have plenty of water in his body to keep alive. About two-thirds of your weight is water. About four-fifths of protoplasm is water. Water helps carry on many of the chemical changes that are necessary to keep living things alive.

Water is also important in our bodies because it helps dissolve materials and helps carry them to different parts. Much water is poured into our digestive organs to help dissolve our food. The blood that carries dissolved materials from one part of the body to another is eighty-one per cent water. Water that

FIG. 109. Milk, fruits, and vegetables are our most important mineral foods. (J. C. Allen-Century photo)

leaves the body through the sweat glands in the skin and through the kidneys carries much waste material out of the body. Water helps keep our bodies cool by evaporating when it is poured on our skin by the sweat glands. Everyone should see that his body receives plenty of water. Almost all our foods contain some water. Juicy fruits and vegetables, such as melons, apples, and tomatoes, are mostly water. (See Table 10, page 176.) However, we must get most of the water that our bodies need in liquid form, either as pure water or in soups, milk, and other beverages.

OF WHAT USES ARE THE MINERALS IN OUR FOODS? When food is burned as completely as it can be, minerals are left. You probably call these minerals ashes, and that is a good name, because chemists call the minerals *ash* when they analyze food.

From the food we eat and the water we drink we must get minerals that will give us all the elements our cells need to build our bodies and to make the chemicals that our bodies need. (Table 10, page 176, gives the percentage of minerals in common foods.) As you learned in Unit 5, we need calcium and phosphorus in rather large amounts to make bones and teeth. New red-blood cells cannot grow without iron and copper. A certain important gland called the *thyroid gland* cannot make its chemical without iodine. Lack of the right amount of iodine often causes a disease called goitre, in which the thyroid gland becomes much enlarged. Sodium, potassium, magnesium, chlorine, manganese, fluorine, and probably other elements are all needed to keep the body working in a healthy manner.

Scientists have learned by analysis and by feeding experiments that most people get all the mineral elements they need except four: calcium, phosphorus, iron, and iodine. We should choose foods with care to make sure of getting enough of these elements. Milk, cheese, meats, and green vegetables furnish large amounts of calcium, phosphorus, and iron. Sea foods are rich in iodine. In the central part of this continent people cannot obtain sea foods easily. Therefore some scientists think that these people should use salt that contains a very small amount of a compound called sodium iodide ($NaI$). As you can tell by the name and the formula, this compound contains iodine. Salt that is mixed with a little sodium iodide is labelled "iodized salt."

WHY ARE VITAMINS IMPORTANT IN OUR FOODS? Usually when we think of diseases, we are thinking about those that are caused by germs or microbes. Strangely enough, some of the most mysterious diseases that man has had to fight are not caused by germs. In 1519 the famous Magellan set out to sail around the world. During the journey across the Pacific Ocean, his sailors' mouths became sore, their gums bled, their joints swelled up, and the men screamed with pain. These sailors had *scurvy*. Scurvy was common on ships that went on long journeys. Another mysterious disease afflicted people in China, Japan, and in many other parts of the world. People would notice that their legs were beginning to feel numb. Later they suffered pain in the calves of their legs. They would get worse and worse until they became paralyzed and died. These people had *beri-beri*. In 1879 nearly 2000 men in the Japanese navy had beri-beri. Even as late as 1930 a Danish whaling ship had fifty-one cases of beri-beri.

Throughout the world, especially in places where people do not get much strong sunlight, many children have soft bones. These bones become crooked because they cannot support the weight put on them. This is caused by a disease called *rickets*. We know now that children who have plenty of sunlight during the summer and take some form of cod-liver oil in winter-time will never suffer with rickets. Another mysterious disease, called *pellagra*, has long been common. In this disease there is a peculiar breaking-out of the hands, feet, and face. Those who have it become nervous and fearful. They cannot sleep at night.

Gradually scientists learned that food had something to do with these four terrible diseases. Magellan's sailors got well when they reached the Philippine Islands, where there was fresh food to eat. Doctors of the British navy learned that the sailors did not get scurvy if they had orange juice or lemon juice to drink. To cure beri-beri, a doctor in the Japanese navy tried an experiment with better food for the men on one ship. The experiment was so successful that his plan was used for all the men in the Japanese navy. Eight years later not a single case of beri-beri was reported in the whole navy.

FIG. 110. If you live on a farm where there are cows, pigs, and other animals, you know how food affects the growth of animals. These two puppies are the same age, and they are the same kind of dog. They were fed on the same food, except that the little one never had any milk to drink.

Another strange fact about disease and food was learned when people found out that oil from the livers of codfish prevented *rickets*. In regions where the people ate much codfish, there was no rickets. Eskimos never had rickets; most of their food was fat and oil from fish. About 1915 Dr. Joseph Goldberger, after long, careful study, proved that people who ate fresh meat and drank milk did not get pellagra. Later he learned that yeast would cure the disease.

All these facts that scientists were learning made them sure that food did something more than give us energy and help us grow. They became sure that there was some mysterious substance in food that helped keep us from getting diseases. So the scientists began to experiment. They experimented by giving different foods to such animals as rats and guinea-pigs. It did not take the scientists long to find out that these animals could not live long on a diet of pure carbohydrates, fats, proteins, minerals, and water. In 1912 a scientist found that only one-half teaspoonful of milk each day, along with the other foods, would keep


FIG. 111. Some of the foods that are rich in vitamins are shown in this picture. (J. C. Allen-Century photo)

a rat healthy, but rats that did not have the milk were not strong and healthy. Then the scientists found that a little yeast powder added to the food of the rats seemed to do the same thing for them as milk. What could be in milk and yeast that had such magic effects?

All over the world scientists began to work on this problem. What one scientist learned, he told to other scientists. Finally scientists were able to prove that there are some strange chemical substances in certain foods that we must all have to keep well. If our bodies do not get these substances, we develop scurvy, beri-beri, rickets, or pellagra, depending on what substance is missing. But we need very small amounts of these chemicals. To keep from getting rickets, a person needs each day a bit of a certain chemical compound only as big as the period at the end of this sentence.

These tremendously important chemicals that keep us well are called *vitamins*. Because they did not know what these chemicals were, scientists named them by letters of the alphabet vitamins A, B, C, D, E, and G. Chemists have now found exactly what chemical compounds some of the vitamins are. They have actually made some of them. They are still studying and experimenting to learn about the others.

Most of us do not need to know just what kind of food contains each kind of vitamin. We get plenty of vitamins in the

FIG. 112. This pig had plenty of the right kind of food to make its bones grow, but it did not get enough of the right kind of vitamin. Therefore the pig developed such a case of rickets that, as shown at the left, it could not stand on its front legs. But daily doses of cod-liver oil cured the pig. (Wisconsin Experiment Station photo)

foods we eat. A good American diet, with plenty of meat, whole-grain bread and cereals, milk and butter, and fresh fruits and vegetables (especially raw tomatoes or lemons or oranges), contains all the vitamins most of us need. Eating more vitamins than you need will not improve your health. Most people do not need to buy medicines and specially prepared foods that are advertised as containing a great deal of vitamins.

There is just one possible danger for most people. Vitamin D, which prevents rickets and helps make good, sound teeth, is made in some foods and in our own bodies by certain invisible rays from the sun. These rays are called *ultra-violet* rays. In winter we wear heavy clothes and stay indoors a great deal. Also, in most parts of our country the sunlight is partly shut off by clouds and by smoke from chimneys much of the time in winter. Thus our bodies may not get enough of this vitamin. In winter growing children should have cod-liver oil, halibut-liver oil, or some other material that contains large amounts of vitamin D. This lack can also be made up by exposing our bodies to the light of a good "sun lamp." However, there are dangers in taking too much vitamin D and too much light from a sun lamp. You should follow your doctor's advice, especially in using a sun lamp.

*Self-Testing Exercises.* 1. Make a table like the one below and fill it in for the different classes of food.

CHARACTERISTICS AND USES OF DIFFERENT CLASSES OF FOODS

| CLASS OF FOOD | ELEMENTS IN THIS FOOD | COMMON SOURCES OF THIS FOOD | USE IN BODY |
|---|---|---|---|
| Carbohydrates<br>Etc. | | | |

2. Make a list of the foods of which you eat the most. After each food in your list write letters or words to show which kind, or kinds, of food materials are found in each food in large amounts. Use Table 10, page 176, to help you.

3. Why is cod-liver oil or some similar substance recommended for almost all babies in the northern regions during the winter? Why do they not need as much of it in the summer?

*Problems to Solve.* 1. If you did Experiment 31 on page 153, you know how to test foods for starch and sugar. You can also test them for fats, proteins, minerals, and water. Try these tests on different foods.

*a*) FATS. Mash a small piece of the food on a sheet of glazed (slick) paper and warm it over a flame. Look for a "grease" spot. This can be most easily seen by holding it up to the light. The light will pass through the spot better than through the rest of the paper. The grease-spot test shows only those foods that contain a rather large amount of fat.

*b*) PROTEINS. Put a small sample of the food in a test-tube. Add a few drops of concentrated nitric acid. Heat the tube gently. If the food contains protein, it will turn yellow. Pour off any extra nitric acid and put in an inch or two of ammonium hydroxide or household ammonia. The ammonia will make the yellow color darker or change it to orange.

*c*) MINERALS. Put a small sample of the food in a shallow iron pan, or in an iron spoon, or on a piece of sheet iron. Heat the under side of the iron as hot as you can and keep it hot until all the food has burned and only a white or gray material is left. This is the mineral matter, or ash, in the food.

*d*) WATER. Plan your own experiments to find whether foods contain water. If you heat them, be sure not to use heat enough to decompose them. By weighing your samples, you can find whether foods contain much or little water.

2. Appoint a committee to look up material on vitamins and make a report to the class. The committee should investigate such things as the discovery of the various vitamins, their chemical composition, and what they do for the body.

3. In the advertisements of foods and on the containers of foods you use at home look for statements that tell what kinds of foods (proteins, carbohydrates, etc.) they are. Make an exhibit of these statements.

FIG. 113. From what you learned in Problem 2, see if you can tell whether or not this girl is eating a well-balanced breakfast.

## ¶ 3. How can you select your foods wisely?

IN SPITE OF ALL WE KNOW ABOUT FOOD, we often do not choose our foods wisely. We may be too lazy! Or we may read so much about foods that we get confused and say, "What's the use? I can never select just the right foods, anyhow." But it is really not very hard to know what to eat. A few simple rules tell us how to choose our food. Since you have studied Problem 2, you will understand the reasons for each rule. In some homes boys and girls, as well as fathers and mothers, may find it hard to follow the rules of a healthful diet. But to keep healthy they should do their best to follow these rules. By careful planning, many families can improve their selection of food without spending any more money.

HOW CAN WE KNOW HOW MUCH FOOD TO EAT? Is your appetite a safe guide in deciding how much food to eat? The answer depends on you and your appetite. Some boys and girls have appetites that are healthy and well trained; such appetites may be followed safely. Some people have never had the chance to eat the most healthful selection of foods. Other people have appetites that have been spoiled; such appetites are a poor guide in eating enough food to keep a person strong and growing. Some appetites are always calling for sweet foods and candy; their owners, if they follow only their appetites, do not eat enough of the better kinds of food.

TABLE 11. Approximate Amount of Food Required to Supply 100 Calories of Heat*

| NAME OF FOOD | PORTION SUPPLYING 100 CALORIES OF HEAT (APPROXIMATE) | WEIGHT OF FOOD (OUNCES) |
|---|---|---|
| COOKED MEATS | | |
| Beef, round, boiled | Small serving | 1.6 |
| Beef, fifth rib, roasted | Small serving | 1.2 |
| Lamb, leg, roasted | Ordinary serving | 1.8 |
| Pork, ham, boiled | Ordinary serving | 1.1 |
| Veal, leg, boiled | Large serving | 2.4 |
| Chicken | Large serving | 3.2 |
| Pork, loin | Very small serving | .97 |
| VEGETABLES | | |
| Asparagus, cooked | Very large serving | 7.19 |
| Beans, baked | Small side dish | 2.66 |
| Beans, string | Five servings | 16.66 |
| Cabbage, fresh | Three servings | 11.0 |
| Corn, sweet | One side dish | 3.5 |
| Onions, cooked | Two large servings | 8.4 |
| Peas, canned | Two servings | 6.3 |
| Potatoes, baked | One good-sized serving | 3.05 |
| Tomatoes, fresh | Four average servings | 15.0 |
| FRUITS | | |
| Apples, raw | Two apples | 7.3 |
| Bananas | One large | 3.5 |
| Cantaloupe | Half ordinary serving | 8.6 |
| Grapefruit | One-half | 7.57 |
| Oranges | One very large | 9.4 |
| Peaches | Three ordinary | 10.0 |
| Pears | One large | 5.40 |
| Strawberries | Two servings | 9.10 |
| DAIRY PRODUCTS | | |
| Butter | One pat | .44 |
| Buttermilk | One and one-half glasses | 9.7 |
| Cheese, full cream | One and one-half cu. in. | .82 |
| Cream | One-quarter ordinary glass | 1.7 |
| Milk, whole | Small glass | 4.9 |
| Hen eggs, boiled | One large egg | 2.1 |
| CAKES, DESSERTS, SWEETS | | |
| Cake, chocolate layer | One-half ordinary piece | .98 |
| Custard, milk | Ordinary cup | 4.29 |
| Doughnuts | Half a doughnut | .8 |
| Pie, apple | One-third piece | 1.3 |
| Pudding, brown betty | Half ordinary serving | 2.0 |
| Sugar, granulated | Three teaspoons or one and one-half lumps | .86 |
| NUTS | | |
| Almonds | Eight to fifteen | .53 |
| Brazil nuts | Three ordinary size | .49 |
| Filberts | Ten nuts | .48 |
| Peanuts | Thirteen, double | .62 |
| Walnuts | About six | .48 |

TABLE 11—CONTINUED

| NAME OF FOOD | PORTION SUPPLYING 100 CALORIES OF HEAT (APPROXIMATE) | WEIGHT OF FOOD (OUNCES) |
|---|---|---|
| CEREALS | | |
| Bread, corn | Small square | 1.3 |
| Bread, white | Ordinary thick slice | 1.3 |
| Corn flakes | Ordinary cereal dish | .97 |
| Crackers, graham | Two | .82 |
| Oatmeal, boiled | One and one-half servings | 5.6 |
| Rice, boiled | Ordinary cereal dish | 3.1 |
| Shredded wheat | One biscuit | .94 |

*Data compiled by Dr. Irving Fisher, Yale University

Some people, especially older persons, so greatly enjoy eating that they become too fat. Such overeating puts a strain on the digestive system. Furthermore, when people eat so much that they become too heavy, there is also an extra strain on the heart and the other parts of the circulatory system. We should be intelligent about how much food we need, in order to guide and control our appetites.

The amount of food a person needs depends upon a number of things. Growing boys and girls need more building material in proportion to their size than an older person needs. A large person needs more food than a small person. A person who is doing hard physical work or exercising vigorously needs more food than a person who gets little exercise. We need more food when we are out in the cold than when we are in a warm place. And finally, people are different in the kinds and amounts of food they need. Foods that are good for most of us may cause indigestion in a few people.

To tell just how much food people should eat, scientists have done two things. First, they have learned how much energy a gram of each kind of food contains. They measure the energy, or *fuel value*, of a food by finding how much heat it gives out when it is completely oxidized. This energy is measured in *calories*. One calorie is the amount of heat needed to make a kilogram (1000 grams) of water one degree hotter by the centigrade scale. You will understand this better if we say that one calorie of heat will raise the temperature of one pound of water about four degrees Fahrenheit. One gram of pure carbohydrate,

when it is oxidized, gives out about 4.1 calories of heat. One gram of pure fat gives out 9.3 calories, and one gram of pure protein gives out, on the average, 4.1 calories. Table 11, on pages 186 and 187, shows the amounts of different kinds of food required to produce 100 calories of energy in the body.

The second thing scientists have done is to study very carefully how much energy different people use in a day. A very complicated apparatus (Figure 114) measures the oxygen a person uses, the carbon dioxide he gives out, the heat he makes, and the amount of work he does. When the scientists know these things, they can figure out how much energy a person's food should give

TABLE 12. Calories Needed by Different Individuals

| INDIVIDUAL | OCCUPATION | CALORIES REQUIRED PER DAY |
|---|---|---|
| Man | Moderately active muscular work | 3500 |
| Man | Light muscular work | 3150 |
| Boy of 15 | | 3150 |
| Man | Sedentary work | 2800 |
| Woman | Moderately active work | 2800 |
| Boy from 13 to 14 | | 2800 |
| Girl from 15 to 16 | | 2800 |
| Woman | Light work | 2450 |
| Boy 12 | | 2450 |
| Girl 13 to 14 | | 2450 |
| Boy 10 to 11 | | 1800 |
| Girl 10 to 12 | | 1800 |

him. Experts who plan diets for large numbers of people consult a table like Table 12 to learn how much energy each person needs. Then they select the proper amounts of food by the use of tables like Table 11. In this way they can work out a good diet for any group of people.

However, you probably do not need to spend much time counting up the number of calories of food energy you need. Each one of us, if he is not sick, should eat enough to keep himself feeling strong and energetic throughout the day. Young people should, of course, eat enough to gain weight gradually. Look at Table 13 on page 190 and compare your weight with the average for your age and height. These averages may not quite fit you. Persons who are broad and heavy-bodied will weigh more than the average

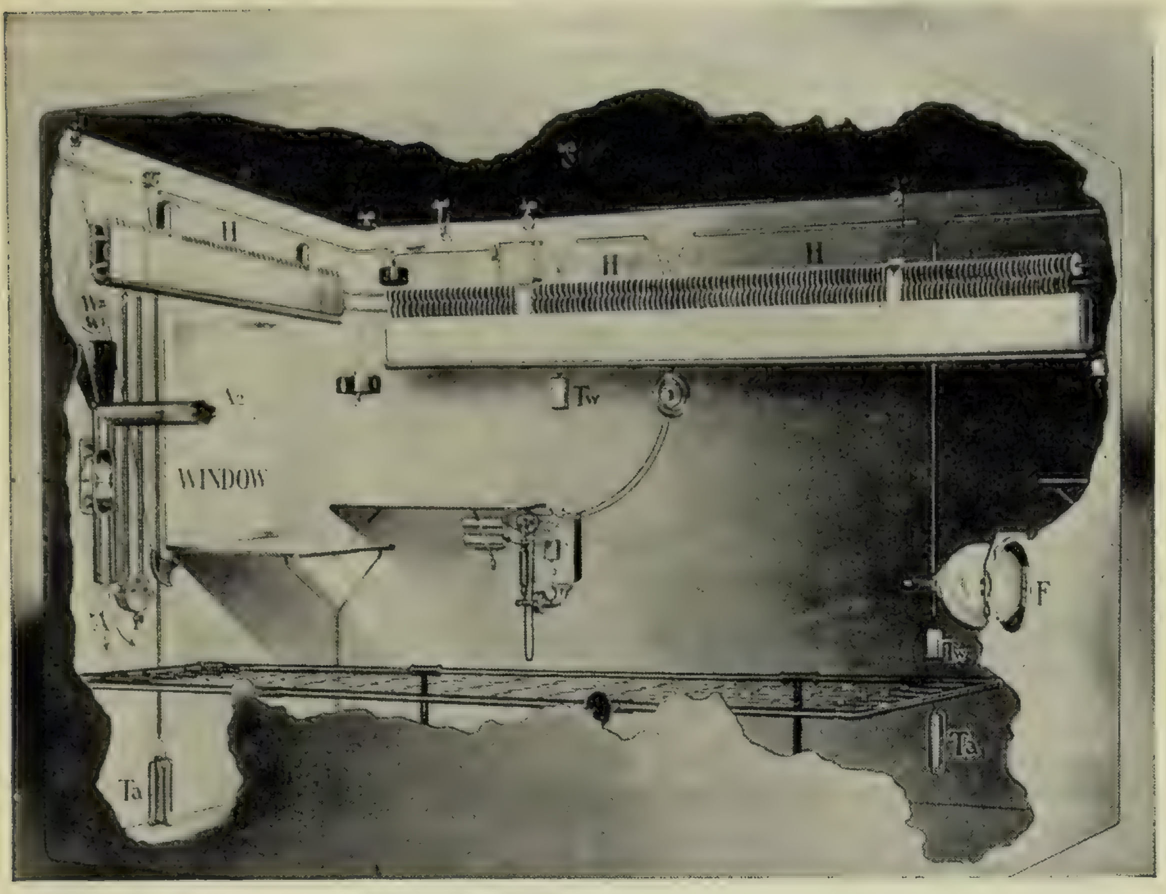


FIG. 114. This is a picture of one kind of apparatus used to measure the amount of energy a person's food gives him. It is really a room full of delicate measuring instruments. You can easily believe that scientists had to solve many problems before they knew how to make this apparatus. (Carnegie Nutrition Laboratory, Washington, D. C.)

for their height. Those who are slender will weigh less. But if your weight is quite far below the average, you probably should eat larger amounts of nourishing foods. On the other hand, if you are much heavier than the average for your age and height, you may need to eat less. Eat protein foods to give your body building material, but avoid overeating of foods that are rich in carbohydrates and fats.

There is one bit of advice that some of you may need. It is this: Do not try to reduce just to be stylish. Young people, especially girls, are naturally plump if they are healthy. And all through your life avoid trying the lazy way to reduce; the lazy way is to take advertised drugs. These remedies are either worthless or dangerous. It is also dangerous for young people to go on a "starvation diet" in order to reduce. If you really need to reduce and cannot do it by self-control in eating and by taking plenty of exercise, talk to your doctor and do what he says.

TABLE 13. HEIGHT-WEIGHT-AGE TABLE‡

| AGE | 11 YR. | | 12 YR. | | 13 YR. | | 14 YR. | | 15 YR. | | 16 YR. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEIGHT | B† | G† | B | G | B | G | B | G | B | G | B | G |
| 46 (Inches) | 49 | 49 | | 49 | | | | | | | | |
| 47 (Inches) | 51 | 51 | 51 | 52 | | | | | | | | |
| 48 (Inches) | 54 | 53 | 54 | 54 | | | | | | | | |
| 49 (Inches) | 55 | 56 | 56 | 58 | | 58 | | 58 | | | | |
| 50 (Inches) | 58 | 61 | 58 | 62 | 59 | 63 | 59 | 64 | 60 | | | |
| 51 (Inches) | 61 | 63 | 61 | 65 | 62 | 66 | 62 | 69 | 63 | | | |
| 52 (Inches) | 64 | 65 | 64 | 67 | 64 | 69 | 65 | 71 | 66 | | | |
| 53 (Inches) | 67 | 68 | 68 | 69 | 68 | 71 | 69 | 73 | 70 | | | |
| 54 (Inches) | 70 | 71 | 71 | 71 | 71 | 73 | 72 | 75 | 73 | | | |
| 55 (Inches) | 73 | 74 | 74 | 75 | 74 | 77 | 74 | 78 | 76 | 79 | 77 | |
| 56 (Inches) | 77 | 78 | 77 | 79 | 78 | 81 | 78 | 83 | 80 | 86 | 81 | 89 |
| 57 (Inches) | 81 | 82 | 81 | 82 | 82 | 84 | 83 | 88 | 83 | 92 | 84 | 96 |
| 58 (Inches) | 84 | 86 | 85 | 86 | 85 | 88 | 86 | 93 | 87 | 96 | 88 | 101 |
| 59 (Inches) | 88 | 90 | 89 | 90 | 89 | 92 | 90 | 96 | 90 | 100 | 90 | 103 |
| 60 (Inches) | 92 | 95 | 92 | 95 | 93 | 97 | 94 | 101 | 95 | 105 | 96 | 108 |
| 61 (Inches) | 95 | 99 | 96 | 100 | 97 | 101 | 99 | 105 | 100 | 108 | 103 | 112 |
| 62 (Inches) | 100 | 104 | 101 | 105 | 102 | 106 | 103 | 109 | 104 | 113 | 107 | 115 |
| 63 (Inches) | 105 | 108 | 106 | 110 | 107 | 110 | 108 | 112 | 110 | 116 | 113 | 117 |
| 64 (Inches) | 108 | 112 | 109 | 114 | 111 | 115 | 113 | 117 | 115 | 119 | 117 | 120 |
| 65 (Inches) | 112 | 116 | 114 | 118 | 117 | 120 | 118 | 121 | 120 | 122 | 122 | 123 |
| 66 (Inches) | 115 | | 117 | 122 | 119 | 124 | 122 | 124 | 125 | 125 | 128 | 128 |
| 67 (Inches) | | | | 126 | 124 | 128 | 128 | 130 | 130 | 131 | 134 | 133 |
| 68 (Inches) | | | | 130 | | 131 | 134 | 133 | 134 | 135 | 137 | 136 |
| 69 (Inches) | | | | | | 134 | 137 | 135 | 139 | 137 | 143 | 138 |
| 70 (Inches) | | | | | | 136 | 143 | 136 | 144 | 138 | 145 | 140 |
| 71 (Inches) | | | | | | 138 | 148 | 138 | 150 | 140 | 151 | 142 |
| 72 (Inches) | | | | | | | | | 153 | | 155 | |
| 73 (Inches) | | | | | | | | | 157 | | 160 | |
| 74 (Inches) | | | | | | | | | 160 | | 164 | |

‡ After tables by Bird T. Baldwin and Thomas D. Wood. Age is taken at the nearest birthday; weight is taken at the nearest pound.

† B represents boys. † G., girls.

In this table the following allowances for clothing, except shoes and sweaters, have been included—BOYS: 35-63 pounds, 3.5 per cent of the net weight; 64 pounds or more, 4 per cent of the net weight. GIRLS: 35-63 pounds, 3 per cent of the net weight; 64-82 pounds, 2.5 per cent of the net weight; 83 pounds or more, 2 per cent of the net weight.

*Self-Testing Exercises.* 1. (*a*) What is a calorie? (*b*) How many calories does Table 12 show that you need in one day?

2. Refer to Table 13, above. Are you overweight or underweight, according to the table? (Be sure to make allowances for your clothing, as shown in the fine print beneath the table.) If you are far above or below the average, what should you do about your diet?

3. State a practical rule that an ordinary person can follow in deciding how much food he should eat.

FIG. 115. This is a good breakfast for a growing boy or girl—oatmeal, toast and butter, cocoa, milk, and baked apple. (American Museum photo)

HOW CAN WE SELECT THE RIGHT KINDS OF FOOD TO EAT? You have learned how important it is to eat different kinds of food so that your body will get everything it needs. At each meal you should eat some food that has a large amount of protein. The animal proteins, such as meat, eggs, milk, and cheese, have the kinds of proteins that your body needs most. However, eating too much protein does little good; it only adds to the cost of your food, because such foods are usually higher priced. With every meal you should eat some carbohydrates and fats to give you energy. Starch and sweet foods have large amounts of carbohydrates in them. Candy is much better for you if it is eaten as part of the dessert than if it is eaten between meals. Butter is one of the most healthful fats.

You should eat plenty of fresh fruit and vegetables, both raw and cooked, and a reasonable amount of whole-wheat products or whole-grain cereals. These kinds of foods fill three needs of your body: (1) They are rich in vitamins that you need to keep healthy. (2) They contain minerals that you need to grow and to keep your body working well. (3) The fibres and indigestible parts of fruits and vegetables fill up the large intestine and stimulate it to empty itself regularly.

Every person should also have plenty of milk. Milk contains valuable carbohydrates, fats, and proteins. It also has an unusual amount of the bone-building mineral elements, calcium and phosphorus. A quart of milk contains more calcium than a growing person needs in a day and more than half enough phosphorus. Milk is also rich in several of the vitamins. Most of us can digest it easily. It is no wonder, then, that milk is considered one of our most valuable foods.

The rules on the next page will help you remember what scientists have learned about the kinds of food we should eat. Most of

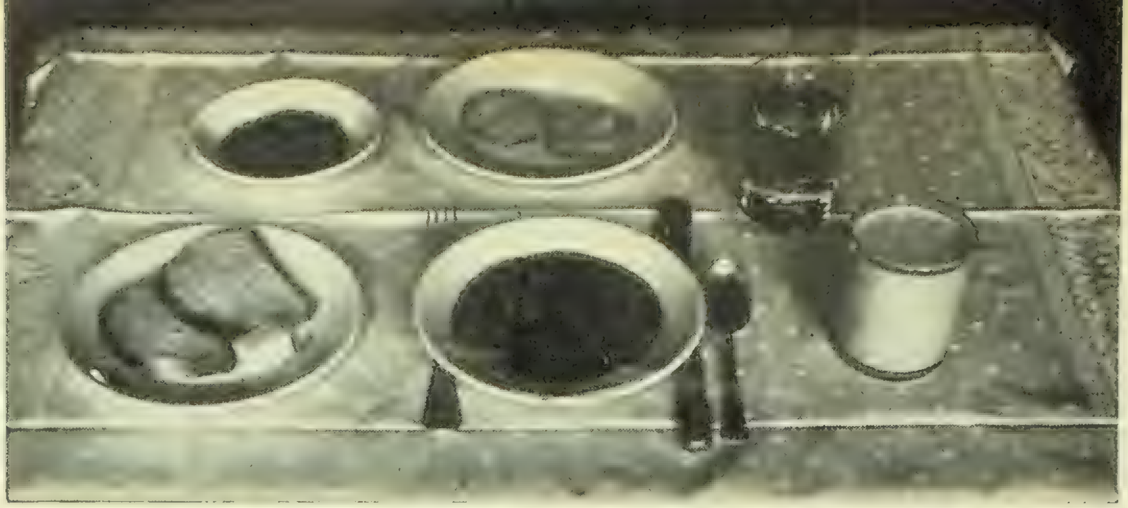

FIG. 116. Cream of tomato soup, milk, white bread and butter, prunes, and cookies at noon will provide plenty of energy and building material for the work and play of the afternoon. (American Museum photo)

you will get the right kinds of food to keep healthy if you use these rules. If you find that you do not have good digestion or do not keep healthy and strong when you follow these rules, make careful changes in your diet or talk to your family doctor and follow his advice.

1. *Eat regularly three meals a day.* If you are very active, you may find that a light lunch of easily digested food in the middle of the morning and again in the middle of the afternoon will make you feel better. However, such lunches should not cause you to eat more than you really need, and they should not regularly be of candy.

2. *Eat a serving of food rich in protein twice a day.* One serving of meat (excluding bacon) is enough for persons who are not doing hard labor.

3. *Eat at least two generous servings of vegetables daily, one of them a green, leafy vegetable.* You have already learned the values of these foods.

4. *Eat two servings of fruit each day, one of them raw.* Oranges, lemons, grapefruit, and tomatoes should be eaten for a valuable vitamin they contain. This vitamin is destroyed by cooking food.

5. *Avoid overeating of sweets.* Candy and other very sweet foods spoil one's appetite for other foods. They are also an important cause of tooth decay.

6. *Eat a whole-grain cereal or two slices of whole-wheat bread each day.*

7. *If you are young, drink at least a quart of milk a day. After you have grown up, use a pint a day.*

8. *Drink four to six glasses of water each day.*

FIG. 117. An evening meal of lamb stew, potato, spinach, whole-wheat bread, butter, milk, and rice pudding completes a day of good nourishing food to take care of all the body's needs. (American Museum photo)

*Self-Testing Exercises.* 1. Copy the eight rules for a good diet, given on page 192. Leave enough room below each rule so that you can write a good-sized paragraph. Close your book and write the reason or reasons for each of the eight rules. If you cannot give these reasons, study this unit until you can do so.

2. After having studied your own eating for a week, tell which of the eight rules you follow and which you do not follow. If there are some of the rules you do not follow, give your reasons for not following them.

*Problems to Solve.* 1. Criticize the set of meals shown below on the basis of the eight rules.

| BREAKFAST | DINNER | SUPPER |
|---|---|---|
| Oatmeal with cream | Corned beef | Corned beef |
| Fried eggs | Boiled dried beans | Fried potatoes |
| Fried ham with gravy | Boiled potatoes | White bread |
| Hot biscuits | White bread | Butter |
| Butter | Butter | Apple-sauce |
| Jam | Jelly | Cake |
| Coffee | Apple pie | Coffee |
| | Coffee | |

2. On his expeditions to the South Pole, Admiral Byrd had to provide food for a large group of active men for several months in a region where no plants grow. What difficulties do you see in providing food to keep the men in good condition? How could the difficulties be solved? If you know the types of food that Admiral Byrd actually took, tell about them. Perhaps you can find out about them by reading.

3. During the World War some submarines and other ships were forced to cease their activities because of scurvy among their crews. Give the reasons why this disease may have broken out.

4. From Table 12 find how many calories of energy you need in a day. Then from Table 11 make up a day's menu that is well selected and gives about the right amount of energy.

5. List some days on which you need more than the usual amount of food and some days when you need less. Give the reasons in each case.

## 4. How does food get to your cells?

YOU HAVE ALREADY LEARNED that the work of your body is done by the individual cells in your body. It is in these cells that your food is oxidized and energy is released to keep your body machine going. But the food that you eat must be changed before it can get to the cells of your body. Before it can pass through the cell walls of the intestine, the blood vessels, and the cells where it is finally used, it must be dissolved. We say that the food must be made *soluble*. Some foods will dissolve in water, but most of the foods you eat, such as bread, meat, and vegetables, will not dissolve until they are changed chemically. When they have changed chemically, they become soluble. The whole matter of changing food so that it can be absorbed by the cells is the work of your *digestive system*. To understand how this digestive system dissolves food, you will need first to know how the digestive system is put together.

WHAT IS THE STRUCTURE OF THE DIGESTIVE SYSTEM? A map of any system of the body is very helpful in understanding its work, just as a road map is helpful in finding your way about in a car. However, you must remember that a map does not show all the details. Figure 118 is a map of the digestive system. Notice that the main part of the digestive system is a tube that goes from the mouth to the *anus* at the lower end of the body. The food tube is much longer than the body. In an adult person it is about thirty feet long. So part of it is coiled inside the abdomen.

The food tube is often called the *alimentary canal*. It is lined with a special layer of cells called the *mucous membrane*. The cells of the mucous membrane give out, or *secrete*, a slimy material called *mucus*. This material lubricates the membrane so that food materials can pass through the tube easily. You can feel the slick mucus on the inside of your mouth.

The part of the food tube just below the mouth is called the *pharynx*. Then comes the *esophagus*. This is a rather narrow tube, but it is able to stretch a great deal. Just below the diaphragm the tube widens to form the *stomach*. After the stomach comes the *small intestine*, which is a coiled tube about twenty-two feet long. The lower end of the small intestine opens into the side of the *large intestine*.

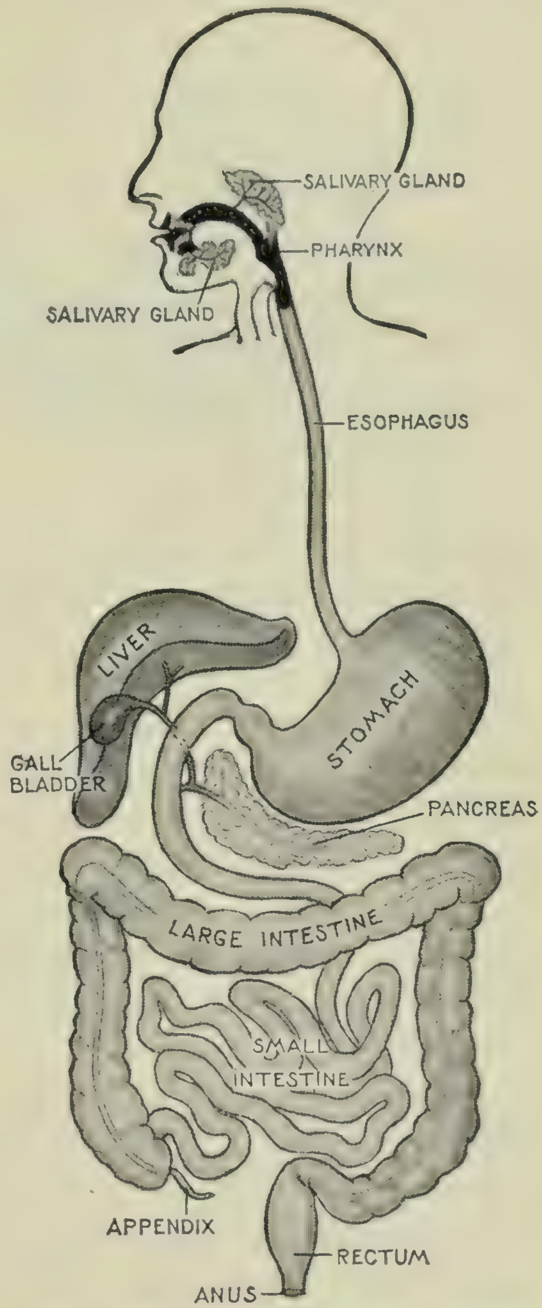

FIG. 118. The digestive system

Notice that some parts of the digestive system are not parts of the food tube. These parts are the *glands* that make chemicals to pour on the food and help dissolve it. Opening into your mouth through tiny tubes are several *salivary glands*. These glands make the watery material, or *saliva*, that keeps your mouth moist. The linings of the stomach and of the small intestines contain many very small glands that make chemicals to help dissolve your food.

Both the *pancreas* and the *liver* are connected to the small intestine by small tubes through which their chemicals are poured on the food as it passes through. The tube coming from the liver is also connected to a kind of sac, the *gall bladder*. The liver fluid, or *bile*, is stored in the gall bladder when it is not needed for the digestion of food. In addition to making chemicals that help with digestion, both the liver and the pancreas have other important duties. For example, the liver helps take waste materials from the blood. You can find out about these other duties by looking in a physiology book.

How is food dissolved? In Problem 2 you learned that there are three important classes of food materials: carbohydrates, such as starch and sugar; proteins, such as lean meat and white of eggs; and fats, such as butter and lard. Each different kind of food needs a different chemical to dissolve it. Thus several different chemicals are used in the food tube, and each different organ of the digestive system has a special work to do in preparing the food for the blood.

In the mouth the teeth cut and grind the food into small bits, so that the chemicals can dissolve it more quickly. While the food is being chewed, the salivary glands pour saliva on it. This is called *mastication*. In order that food may be thoroughly masticated, a person must eat slowly. The chief value of saliva is to moisten the food and to lubricate it, so that we can swallow it easily. However, saliva contains a substance that helps in the chemical digestion of food. You can watch this chemical digest one kind of food in a test-tube.

*Experiment* 39. HOW DOES SALIVA HELP DISSOLVE FOOD? (*a*) Put a lump of laundry starch about the size of a large pea or an equal amount of corn-starch into a beaker or pan. Add about one-third of a glass of cool water. Mix the starch thoroughly with the water and boil it. Then cool the mixture by adding an equal amount of cool water to it. Notice the appearance of the starch mixture. Has the starch dissolved? Pour a little of the mixture into a test-tube and add one or two drops of weak iodine solution. What color do you get?

*b*) Put a piece of water-soaked cloth or a thin layer of soaked absorbent cotton in the bottom of a glass funnel or clean metal funnel and stand it in a test-tube. Collect saliva in the funnel until the test-tube is at least one-fourth full of clear liquid. Test a little of the saliva with iodine as you did the starch mixture. Does it change color?

*c*) Fill the tube that contains the saliva with starch mixture and mix the two liquids thoroughly. After two or three minutes compare the appearance of the liquid in this tube with a sample of the starch mixture poured into another tube. Does the starch seem to have dissolved?

Test some of the starch-saliva mixture with iodine in a separate test-tube. It should no longer show the color caused by starch and

iodine. What has become of the starch? If the starch has not entirely disappeared, let the mixture stand longer and test again. (The results of this experiment will be better if the starch mixture and the saliva can be kept at the temperature of the body by standing the test-tubes in warm water.)

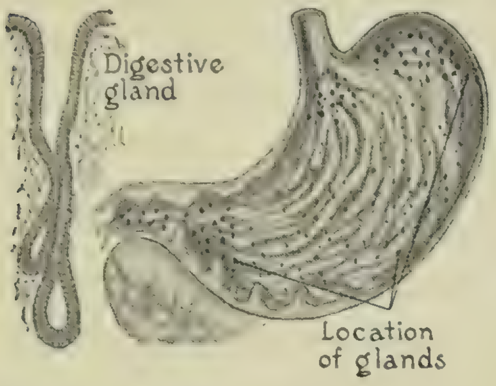


FIG. 119. The black dots show about how the gastric glands are located in the walls of the stomach. At the left is a gland as it looks when it is magnified thousands of times.

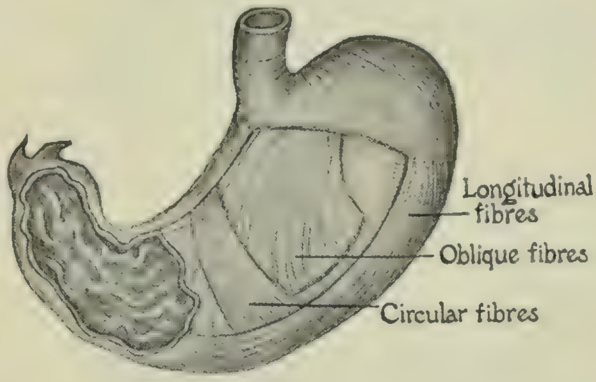


FIG. 120. Muscles of the stomach. You can see that the stomach walls are made up of sheets of muscle running in different directions. These muscles expand and contract to churn the food in the stomach.

Experiment 39 shows that saliva contains some substance that changes starch into another material. Chemical tests show that the new material is one kind of sugar. This sugar is soluble and can be absorbed into the blood. Thorough chewing helps digestion by grinding the food into tiny bits and by giving time for the chemical in the saliva to change the starch to sugar, or digest it.

When we swallow, a layer of muscles around the esophagus pushes the food or drink from the throat into the stomach. The stomach is important as a place to store a meal, but much digestion also takes place in the stomach. Tiny glands in the lining of the stomach (Figure 119) pour a mixture of chemicals, called *gastric juice*, on the food. One of these chemicals is the sour hydrochloric acid. Another, called *pepsin*, changes proteins so that they can dissolve. Strong layers of muscle fibres in the wall of the stomach (Figure 120) contract and expand to stir the food and mix it with the gastric juice. After the food is made into a pasty, half-liquid material, it is pushed little by little into the small intestine.

As the stomach pushes the partly digested food into the upper end of the small intestine, bile from the liver and *pancreatic juice* from the pancreas are poured into the intestine to mix with the food. The tiny glands in the lining of the intestine also pour a digestive juice on the food. The pancreatic juice contains chemicals that help dissolve all three classes of food—fats, carbohydrates, and proteins. Bile helps digest the fats, and the intestinal juice helps digest the carbohydrates and proteins.

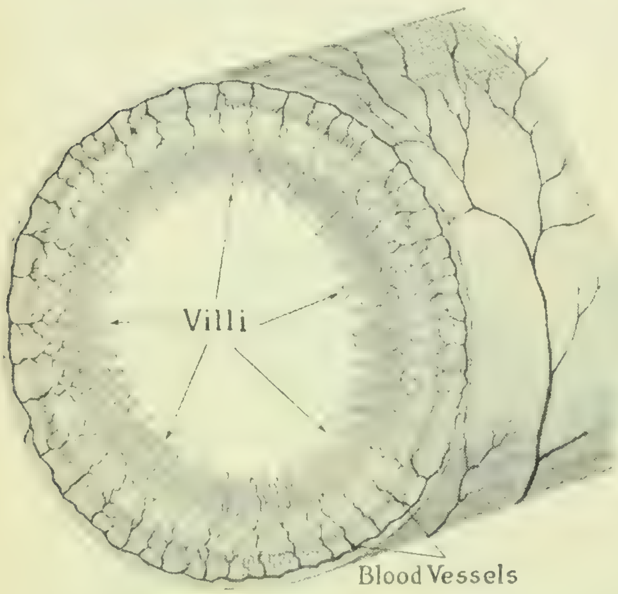

FIG. 121. Villi of the small intestine highly magnified

On the average, food requires about four hours to pass from one end of the small intestine to the other. In this organ the digestion of the food is completed, and the dissolved food is absorbed into the blood.

*Self-Testing Exercises.* 1. What does the digestive system do to make food usable by your body?

2. Close your book and draw a "map" of the food tube. Show where the liver and pancreas pour their chemicals into the tube.

3. Make a list of the glands that pour digestive chemicals into the food tube. Study Figure 118 for help in answering.

4. What does the word *soluble* mean?

5. When saliva is mixed with cooked starch in water, the starch gradually disappears. What becomes of it?

6. State two ways in which the muscles of the food tube help dissolve your food.

7. Explain exactly how the different chemicals from the glands along the food tube help dissolve food?

HOW DOES THE DISSOLVED FOOD GET INTO THE BLOOD? The dissolved food soaks into the lining of the small intestine almost as fast as it is digested. In order to take in the food so rapidly, the intestine must be well fitted for this work. In several ways the intestine is well fitted for rapidly absorbing the food: (1) It has a very thin lining. (2) It contains a great many *capil-*

*laries*. Capillaries are tiny blood tubes that are found in all parts of the body. Their walls are only one cell thick. (3) A great deal of the lining of the small intestine can touch the food; that is, the lining has a large area.

The intestine has a large area for two reasons. In the first place, the small intestine of an adult is about twenty-two feet long. Besides this, it has thousands of tiny "fingers" about one twenty-fifth of an inch long that stick out into the liquid in the intestine and help soak in the food (Figure 121). These tiny fingers are called *villi* (singular, *villus*). In some parts of the intestine these villi make the absorbing surface fifteen times as much as it would be if the inside of the tube were perfectly smooth. This means that, with the help of the villi, those parts of the intestine can take in digested food fifteen times as fast as they could if there were no villi.

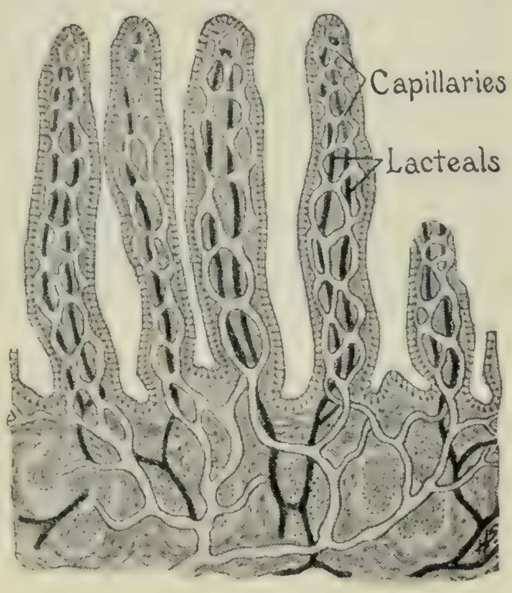

FIG. 122. A section view of villi

The dissolved carbohydrates go into the blood that is flowing through the capillaries in the villi. Digested fats go into small tubes called *lacteals* and then into a long tube that finally empties into a vein near the left shoulder. Scientists do not yet know why one kind of food goes into the lacteals, while the other kinds go into the capillaries. Either way, however, the food finally gets into the blood to be carried near the cells that need it.

By the time the food has reached the lower end of the small intestine, most of the food that will dissolve has been dissolved and absorbed through the walls into the blood stream. The part of the food that has not digested and a good deal of water that is mixed with it are pushed on into the large intestine. The large intestine is much shorter than the small intestine, but it has a larger diameter. Here the extra water is absorbed from the worked-over food, so that the body will not lose it. Then the undigested food is gradually pushed along toward the lower end

of the large intestine and stored. From time to time, it is passed out of the body.

HOW CAN WE HELP OUR DIGESTIVE SYSTEMS? Probably the best help you can give your digestive system is to keep yourself happy and interested in life. Worry, anger, and unhappiness in some way influence the work of the digestive system and may cause actual illness. It is especially harmful to be unhappy and tense at meal-time. These emotional disturbances slow down the usual secretion and movements of the digestive organs. Another thing that often upsets the digestive organs is to engage in vigorous physical activity immediately after a heavy meal. When this is done, the body sends to the muscles the blood that should be going to the digestive organs.

The waste food material that is stored in the large intestine contains large numbers of bacteria. These bacteria are usually quite harmless to the body. In fact, in some kinds of animals these bacteria actually help digest the food. However, these bacteria live on the remains of the food and cause chemical changes in it that are somewhat like decay. It is usually best, therefore, that the materials left over from digestion should not be kept in the large intestine for more than a day. If these waste materials are not evacuated naturally once a day, drink a glass of warm water when you go to bed at night and also when you get up in the morning. Also, eat more fruit, vegetables, and coarse foods, such as bran bread. In most cases relief will be obtained if these things are done. Furthermore, it is wise to heed the sensations which indicate the necessity for evacuation whenever they occur. It is a bad practice to get the habit of using *cathartics*, or *laxatives*, whenever you are constipated. Treat your digestive system wisely, and it will do its work well.

You can also help your digestive organs by the way you eat. The digestive chemicals can dissolve small particles much more quickly than large ones. To chew food well requires that you form correct habits of eating and that you keep your teeth in condition to do their work effectively. After your permanent set of teeth has grown, you cannot get new ones to take their place. The use and appearance of your teeth is so important that you should take better care of them than you would of jewels.

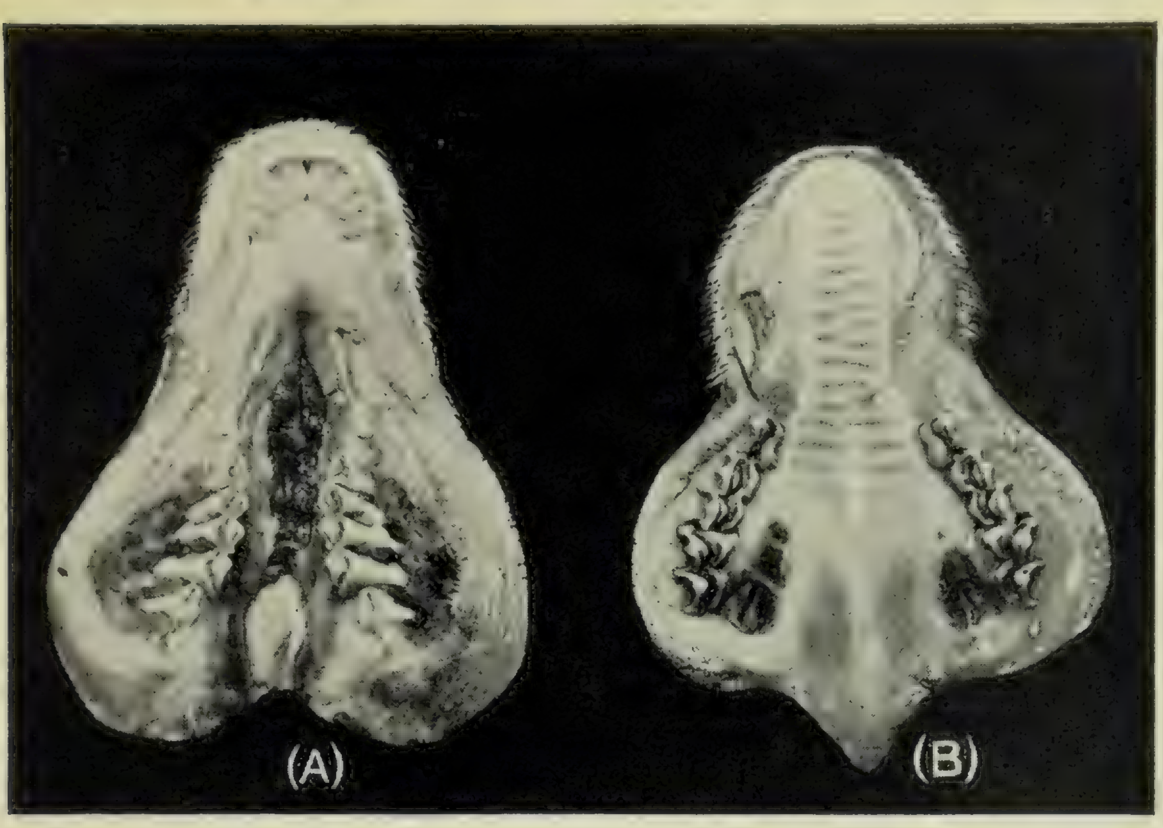


FIG. 123. Crooked teeth developed in a goat because of faulty mineral diet. Note that the lower teeth (A) cannot properly meet the upper teeth (B). The dark spots in (B) are holes made in the roof of the mouth by the failure of the teeth to come together. (Cornell University Animal Nutrition Laboratory)

Unfortunately, the teeth are likely to decay. Scientists have never found out just what causes tooth decay. They do know that there is less decay when we eat a good healthy diet, exercise the teeth and jaws by chewing firm foods, and keep the teeth clean. The time to brush the teeth is directly after eating. The most recent discoveries of scientists show clearly that eating much sugar, candy, and other carbohydrates makes the teeth decay more rapidly. Holes, or *cavities*, in teeth can be filled by a dentist, and the decay will usually stop. It is up to each one of us to keep his teeth clean and to have a dentist inspect them two or three times a year.

Still another way to help your digestive system is to choose your food with a reasonable amount of care. Vitamins help keep the lining of the food tube in good condition. Fruits and vegetables give the teeth and jaws exercise that seems to help in keeping the teeth and gums in good condition. They also contain a rather large amount of fibres and other indigestible materials. These

materials fill up the large intestine and help make the intestine empty itself regularly. Whole-wheat foods are helpful in the same way.

*Self-Testing Exercises.* 1. Give three reasons why the small intestine can absorb digested food quite rapidly.

2. How do digested carbohydrates get into the blood? Digested fats?

3. What happens to any food that does not dissolve?

4. Tell briefly but accurately what happens to a piece of whole-wheat bread (*a*) in the mouth, (*b*) in the stomach, (*c*) in the small intestine, and (*d*) in the large intestine. Remember that the bread contains all three classes of food material and some parts that are not digestible.

5. State four important ways of keeping your digestive system in good condition.

*Problems to Solve.* 1. Chew a dry cracker for a long time. Notice carefully to see if there is a change in its taste. If so, describe the change and explain why the taste changes.

2. Suppose that folds and villi increase the area of the entire small intestine to eight times what it would be if it were smooth on the inside. How long would the small intestine need to be if it were smooth instead of being lined with folds and villi?

3. Can you show that the flow of the saliva into the mouth is influenced by what you think?

4. Read in physiology or other reference books to find out what duties the liver has in addition to the secreting of bile.

5. What is peculiar about the circulation of blood to the liver? Study diagrams of the circulatory system to solve this problem.

6. How might a quarrel at meal-time cause indigestion?

## Looking Back at Unit 6

1. Write down all the principles, or big ideas, of science that you have learned from this unit. State them in complete sentences.

2. Show that you know the meaning of each of these words:

| | | | |
|---|---|---|---|
| *vitamin* | *calorie* | *fuel value* | *fuel foods* |
| *protein* | *digestion* | *gastric juice* | *rickets* |
| *capillary* | *bile* | *pancreatic juice* | *villi* |
| *energy foods* | *gland* | *salivary glands* | *lacteals* |
| *pepsin* | *pellagra* | *beri-beri* | *scurvy* |

FIG. 124. Many people take cod-liver or halibut-liver oil, which contains large amounts of vitamins, to help keep their bodies in good condition, especially in winter, when it is harder to get plenty of sunshine, fresh air, and exercise. This test room, used by a manufacturer of fish oils, has 1000 cages of rats. The rats are given the oil regularly as a test to be sure that the oil has the proper vitamins in it. (Parke, Davis photo)

## Additional Exercises

1. The temperature of a reptile's body is very nearly the same temperature as that of its surroundings. The body temperature of birds is higher than that of man. Would a lizard (reptile) or a bird of the same weight need the larger amount of food? Why?

2. Compare the materials we put into an automobile or a locomotive to make it go with the materials we must put into our bodies. Remember to consider all four requirements of the body, as given on page 174.

3. Make a drawing of your mouth, showing the number of teeth you have. Find out the names of the different kinds of teeth. Your dentist will be glad to help you.

4. Why do we need more food in winter than in summer?

5. Why does a person get much hotter when he exercises?

6. Use Tables 11 and 12 to make up a satisfactory menu for a man who is quite active all day and another menu for a man who sits at a desk all day.

7. In proportion to their weights, why do boys and girls need more food than men and women?

8. List some days on which you need more than the usual amount of food and some days when you need less. Give the reasons in each case.

## Books to Read

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Howard, Ethel K. *How We Get Our Food*. Harcourt, 1939.

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Rose, Mary S. *The Foundations of Nutrition* (pages 237-300). Macmillan, 1931.

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It has taken man a long time to learn how the human body works. For thousands of years he did not even know that the blood is pumped through the body in a steady stream by the heart. Aristotle thought that the blood was made by the liver and used up by the body. Other thinkers believed that the blood flowed by itself, fast in some places and slowly in others.

About 300 years ago, William Harvey, an English physician, proved that the blood is pumped in a steady stream throughout the body. In this picture he is showing how the heart is made so that the blood is pumped out of one side of the heart, goes through the body, and flows back into the other side of the heart. When you have studied this unit, you will understand why this was one of the greatest discoveries ever made about the human body. (Ewing Galloway photo)

# UNIT 7

# How Can You Keep Yourself in Good Physical Condition?

## Looking Ahead to Unit 7

THE MODERN AUTOMOBILE is an interesting and wonderful machine. Early automobiles so often failed to run that there were many jokes about them. But today the automobile has been so improved that we can drive thousands and thousands of miles with practically no trouble except to see that the car has fuel, oil, and water. Inside each car is an electrical system, an oil system, a water or cooling system, a fuel system, and many other parts. Each system and part is connected to the others, so that they automatically work together to make the car go.

Some day you probably will learn to drive one of these complicated machines. Your father or a teacher will help you learn what each of the different systems does to make the car run, why it starts when you turn a certain gadget or push that lever and release this one, how it burns gasoline, and why it must have oil and water. Not only will you learn the main things about how the car works, but you will learn the "rules of the road" and the dangers of driving and how to avoid them. All these things you will learn so that you can drive a car intelligently.

However, you are already "driving" a more complicated and wonderful "machine" than an automobile. This machine is your own body. What do you know about how it works? What makes it go? What different systems are found inside it? What does each one do to keep the body running smoothly? What is most liable to go wrong with its machinery, and how can trouble be prevented?

No matter where you live or what you do, your first problem is that of keeping well, for your efficiency, your comfort, and your happiness depend upon your health. Our present indoor life

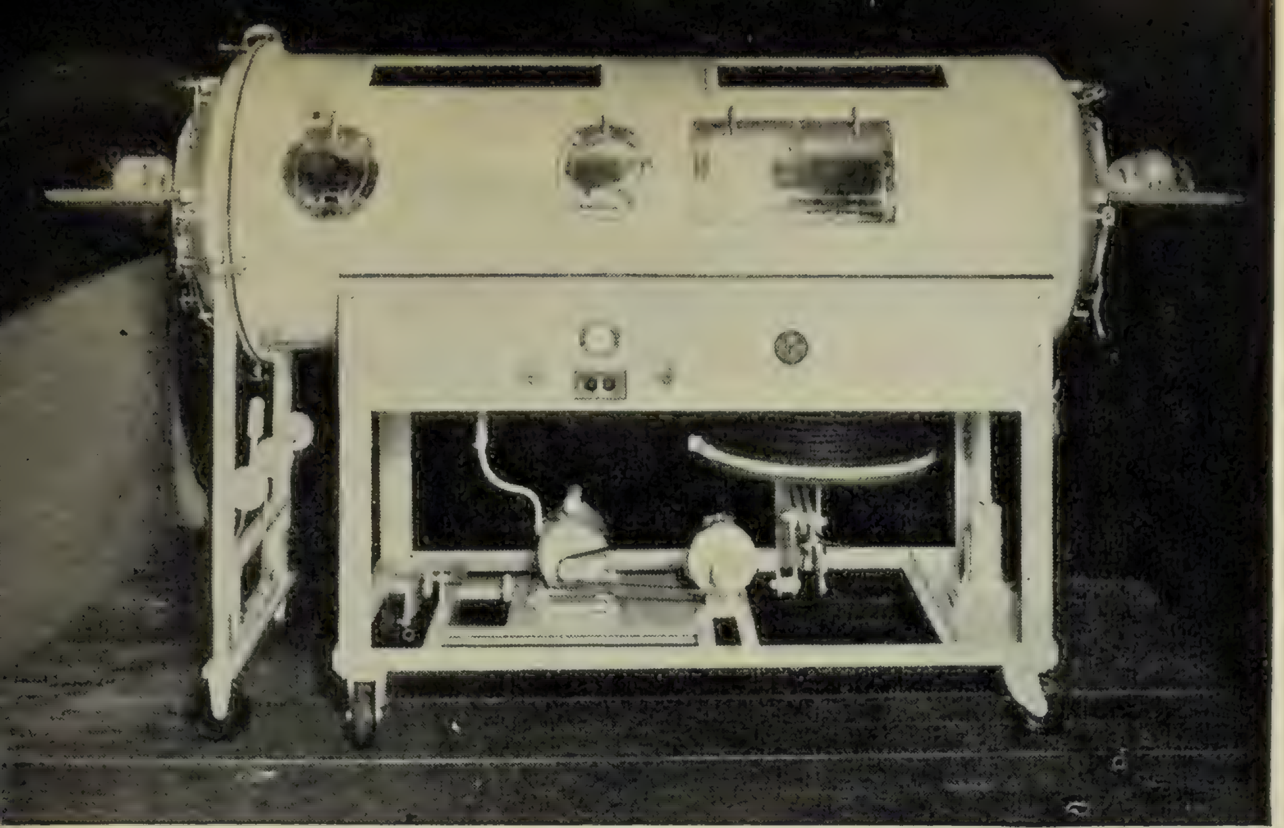


Fig. 125. The famous "iron lung," invented only a few years ago, has saved many lives. In certain kinds of diseases the chest muscles become paralyzed. They cannot raise and lower the chest for breathing. In the "iron lung" the air-pressure is alternately increased and decreased, which forces the chest to move as it does when a person breathes naturally. In time the chest muscles begin to do their work again, and the person's life is saved. (Iron Lung Company of America photo)

makes the problem of keeping well more complicated than it was in the days when people spent most of their time outdoors. Millions of men and women do no hard physical work. This makes it necessary for them to obtain their exercise after work hours. In the business world the struggle has become so intense that men and even women must keep always "on the job" in order to earn a living or to run a business successfully. This "speeding up" of life in the modern world has resulted in a greater strain on the human body and has required us to pay careful attention to our bodily needs.

If you do not already know the main things about how your body is put together and how it works, this unit will help you understand them. The unit will not be able to tell you everything that is worth-while for you to know about your body and its health. However, it will tell you the main things that you need to know to keep physically fit. Furthermore, it will show you how you can go on learning by yourself. In addition to what you will discover from your study of the unit, the unit is the foundation for further learning.

## 1. How is the human body put together?

HOW IS THE FRAMEWORK OF THE BODY CONSTRUCTED? You know that you have bones in your body. Yet the bones of your framework usually give you so little trouble and require so little attention that you know very little about them. There are more than 200 different bones in the human body, all nicely fitted together at the *joints*. If you grow to be a person of average size, all your bones together will weigh about twenty pounds.

FIG. 126

By looking at a human skeleton like that in Figure 126, you quickly see that there is a central column of bones to which the ribs and the bones of our arms and legs are attached. This column of bones is the backbone (Figure 128). Each piece of the backbone is called a *vertebra* (plural, *vertebrae*). Each vertebra has several projections to which muscles are attached.

But the backbone is not all bone. Between each vertebra and the next one is a pad of flexible *cartilage*. When we find cartilage in meat, we call it *gristle*. Your nose and ears contain cartilage that gives them shape and holds them up, yet allows them to be flexible. As you walk, the cartilage pads in your backbone absorb the jar of each step, so that very little of it reaches the skull, that is mounted on the upper end of the backbone. Curves in the backbone also absorb some of the shock. These curves help make the backbone "springy."

At the shoulders there is a set of special bones, called the *shoulder girdle*, to which the arms are attached. The shoulder girdle includes the collar bones and shoulder blades. At the hips is the hip girdle, or *pelvis*, to which the leg bones are attached. In front is the *breast-bone*.

Some of the bones of your body, such as those of the head, are

joined together so that they cannot slip past one another. However, in most parts of your body the bones can move on one

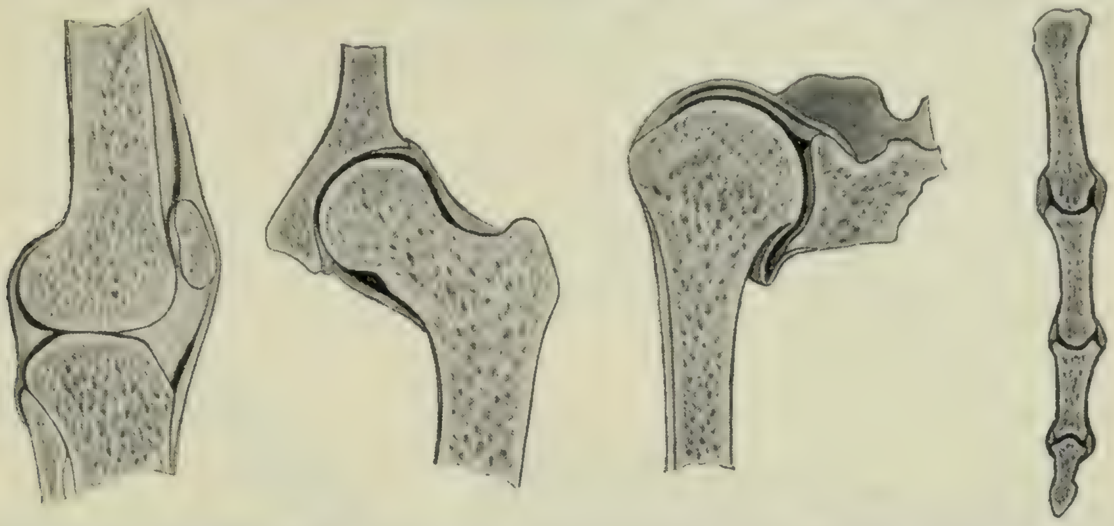


FIG. 127. At the left is a hinge joint in the knee. Notice the *knee cap*, the small oval-shaped bone at the knee. Second from the left is a ball-and-socket joint in the hip. Next to it is a ball-and-socket joint in the shoulder. At the right are hinge joints in the fingers.

another at the joints. Joints may be of the *hinge* type, such as you have in your knees and your fingers, or they may be *ball-and-socket* joints, such as you have in your hips and neck. Hinge joints allow a back-and-forth movement, while ball-and-socket joints allow a twisting movement. Tough sheets and bands of material, called *ligaments*, bind the bones together at the joints.

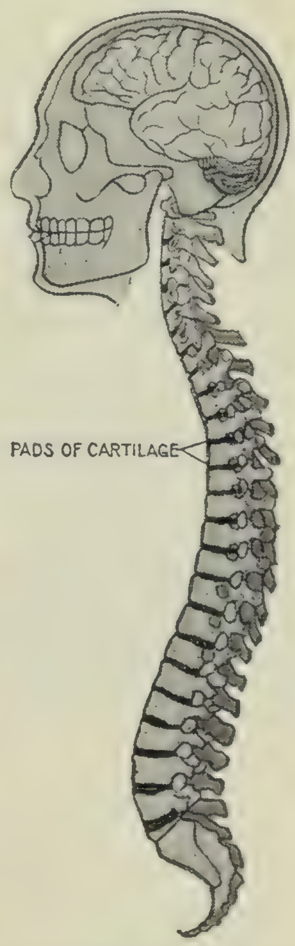



FIG. 128

Sometimes an unusual twist or an accident stretches the ligaments and makes the joint sore and "stiff." We say that the joint has been *sprained*. The soreness warns us not to use that joint freely until the cells have repaired the damage. A pull or a twist may even pull the bones apart until they slip out of their usual places; then we say that we have a *dislocation*, or that the bone is "out of place." Of course, the remedy for a dislocated joint is to pull the bones apart again and let them go back into their usual places.

The movement of your body is made possible by the *skeletal muscles*; that is, the muscles

that are attached to the bones. By feeling the calf of your leg or the large *biceps* muscle in the upper arm, you can discover the shape of most muscles. They have a thick central part and become smaller toward each end. At each end the connective tissue of most muscles extends out to form a strong white cord, or *tendon*, that is attached to the bone. When the cells of one set of muscles contract, the muscles shorten and move the bone. Another set of muscles pulls the bone back to its former position.

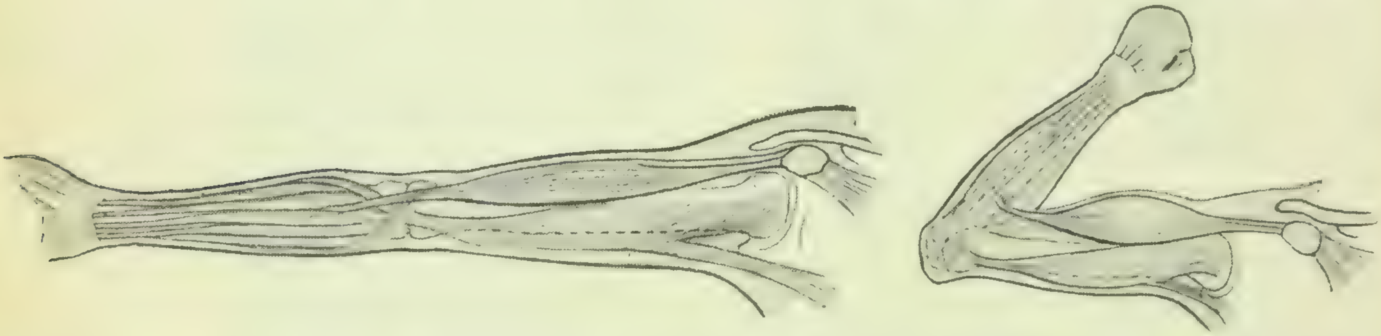


FIG. 129. The muscles of an arm. Notice the different shape of the muscles when the arm is bent at the elbow.

This skeleton of yours is a very necessary part of your body. Without it you would be as soft and flabby as an earthworm. It provides the framework upon which the rest of your body is built, and, as you can see, the shape of your body is determined by the shape of your skeleton. Furthermore, certain parts of the skeleton, such as the skull and ribs, protect the delicate parts of your body from injury. Your framework is rigid enough to hold your body in shape and flexible enough to allow its parts to move.

*Self-Testing Exercises.* 1. List the main sections or divisions of your body's framework. Begin with the backbone.

2. What are some of the advantages of having cartilage in your skeleton?

3. State three important uses of the skeleton in your body.

4. What do joints do for your body?

5. What is the main use of the ligaments around joints?

6. Name two important kinds of joints and tell how they are different.

7. What is a sprain? A dislocation?

8. How do muscles work?

*Problems to Solve.* 1. How many hinge joints can you find in your body? How many ball-and-socket joints?

2. If possible, get a chicken joint or a cow or sheep joint and examine it carefully. Notice (*a*) how the bones are shaped to fit together at the joint and (*b*) the ligaments that hold the bones together.

3. See if you can find any tendons in your body.

WHY IS A CORRECT POSTURE NECESSARY? Inside your body, as you know, are many internal organs, such as your lungs, your heart, your stomach, and your intestines. If you stand, sit, and walk correctly, these organs are assured of enough space inside your body so that they will not be crowded. On the other hand, a person who slouches forward when he stands or walks pushes the internal organs together and cramps them. The same things happen when a person slumps in a chair. The result is often poor digestion, constipation, headache, and a decreased efficiency of the lungs. Poor posture also puts a strain on the skeletal system and may cause pain, fatigue, and nervousness.

In addition to the effects of bad posture upon the internal organs, there is another quite important point to consider, namely, your personal appearance. There is nothing more unsightly than bad posture in standing, walking, and sitting. Awkwardness is largely a matter of bad posture. Good posture helps a person overcome bashfulness and the feeling of being ill at ease. You can see that this is true if you will watch some one of your friends who is always at ease in groups of people.

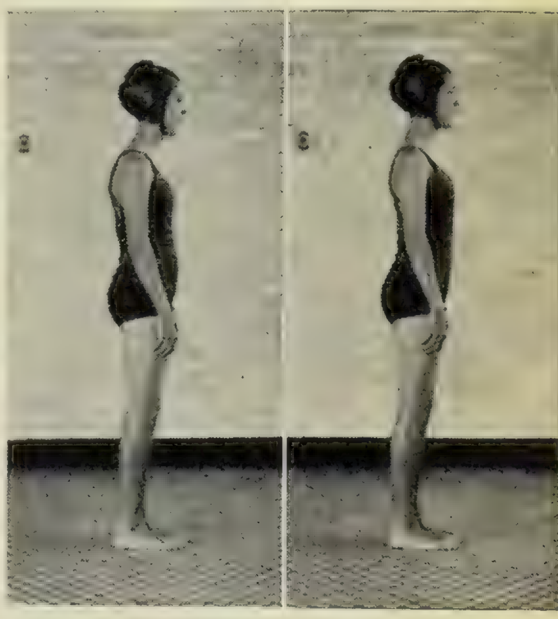


FIG. 130. At the left is shown a faulty standing posture. At the right is the correct standing posture.

It is practically impossible to tell you in a book just how to improve your posture. Posture is largely an individual matter. In your school, however, there is probably a director of physical education or some teacher who has made a special study of this. He or she can tell you whether your posture is good or bad, and what to do about it. The important thing to know is that you must correct your posture while you are young. The sooner you find out whether your posture is good or bad and start to correct any faults that you may

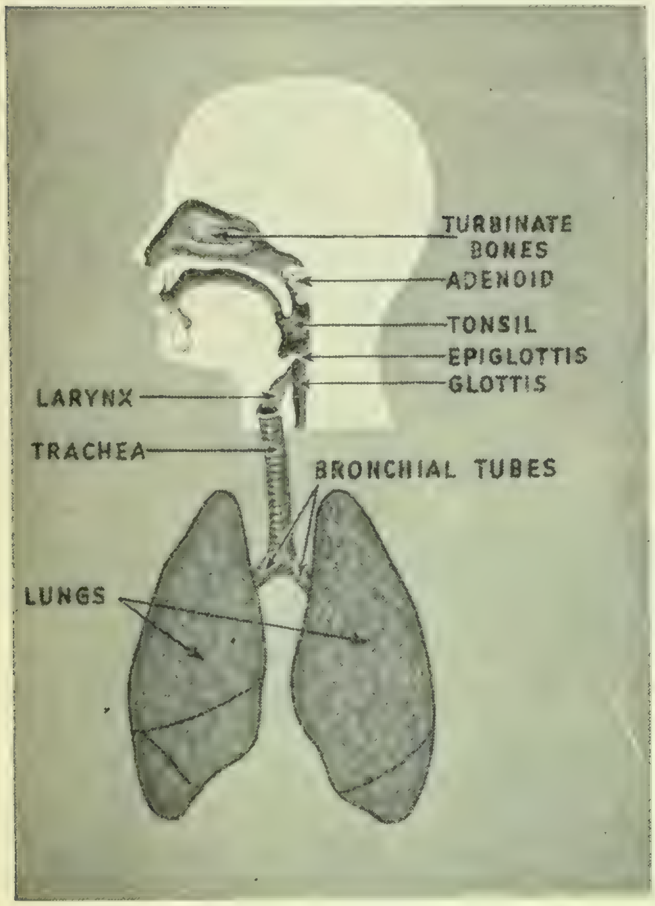



FIG. 131. The breathing system

have, the easier it will be to get the results that you want.

*Self-Testing Exercises.* 1. Write a paragraph about the importance of good posture.

2. Watch other pupils walking, sitting, and studying. Make a list of the ways in which they can improve their posture. When you have made the list, examine your own posture to see if it can be improved.

## 2. How does your body get its supply of oxygen?

HOW DO THE LUNGS WORK? We live at the bottom of an ocean of air. As you know, this air is about one-fifth oxygen. To carry on the activities of living, your body must be able to take some of this oxygen out of the air and distribute it to every one of its cells. You know that air goes into your lungs when you breathe in, or *inhale*, and that used air goes out when you breathe out, or *exhale*. Now let us see what happens to the air when it goes into your body.

Let us follow some air as you breathe it in. Figure 131 will help you get a clear picture of its journey. First the air goes into your nose, and then into your throat. In the throat the air goes down across the food tube and enters an opening in front of the esophagus, called the *glottis*. Just above the glottis is a little flap, called the *epiglottis*. This flap covers the glottis when we swallow, so that no food or water will go down into the lungs.

The air next enters the voice-box, or *larynx*. You call the front side of the larynx your "Adam's apple." In the larynx the air goes through a narrow slit between two bands of tissue that vibrate to make the sounds of the voice. These bands are the *vocal cords*. From the larynx the air goes down a rather large tube, the windpipe, or *trachea*. About six inches below the

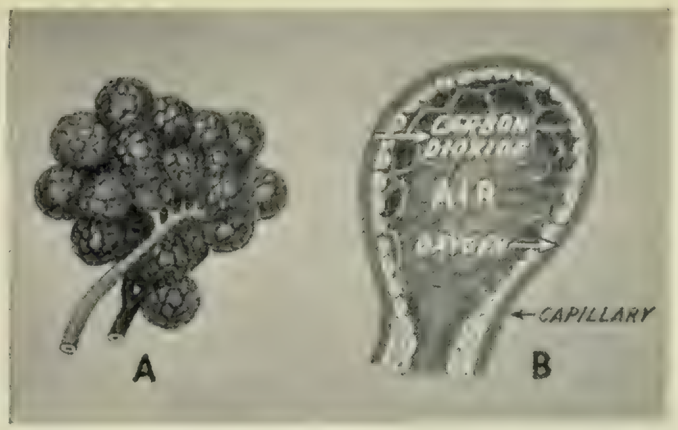



FIG. 132. The lungs are divided into many tiny cavities, or *air sacs*. Drawing A shows a group of air sacs. Notice how they are covered by a network of capillaries. Drawing B shows one air sac as it would look if split open. Of course, both drawings are highly magnified.

"Adam's apple" the air is separated into two parts by the *bronchial tubes*. One part goes into a bronchial tube that enters the right lung, and the other part goes into a bronchial tube that enters the left lung. If possible, examine some real lungs.

*Experiment 40.* WHAT IS THE NATURE OF THE LUNGS? (*a*) Examine the lungs of a sheep. These organs are about the size of a person's lungs. Find a rather large tube, the windpipe, or trachea, connected to both lungs. This tube will sometimes have been split open by meat inspectors. If so, you will be able to see many little tubes leading into the lungs from the lower part of the windpipe. You will also be able to see the many rings of cartilage that held the windpipe open. (See Figure 131.) Feel the lungs with your fingers. Are they firm and heavy or light and spongy?

*b*) Get a rather large glass tube about a foot long and round the edges by holding the end in a glass flame until they are no longer sharp. When the tube is cool, push it into one of the bronchial tubes and blow until the part of the lung connected to that bronchial tube is blown full of air. Its appearance will change and become more like that of a natural lung. Release the air and notice what happens to the lung. By blowing air into the lung and then releasing the air you can imitate the movements of the lungs during breathing.

With a sharp knife cut off a bit of lung that has been blown up. Look carefully at the cut edge. Can you see some very tiny tubes? Can you find, also, some almost invisible air bubbles? These tiny bubbles are the *air sacs* at the ends of the tubes (Figure 132A).

Once inside the lungs, the air runs into smaller and smaller bronchial tubes that fork like the branches of a tree. These branches become smaller and smaller until they reach into every part of the lungs. At the ends of the very finest bronchial tubes the air goes into many tiny cup-shaped cavities (Figure 132A)

arranged all around the tubes, somewhat like grapes on a stem. These tiny cavities are the *air sacs.* Here only the thin wall of the air sac and the thin wall of a capillary lie between the blood and the air. Therefore the oxygen passes easily through the walls into the blood.

The two lungs fill almost the whole chest cavity except the part filled by the heart and windpipe. The lungs are very light, spongy organs because they contain so many bronchial tubes and air sacs. Blood vessels run all through the lungs to carry blood to each air sac and back again to the heart. No one has been able to count all the air sacs in a lung. However, one careful scientist has estimated that the lungs of a grown person contain 600,000,000 air sacs. If the linings of all these sacs could be formed into a single sheet of material, there would be enough to cover the walls of a room fifteen feet wide, twenty feet long, and ten feet high. Can you see why so much lining is useful in the lungs?

HOW DOES THE BLOOD EXCHANGE CARBON DIOXIDE FOR OXYGEN? Figure 132B will help you understand what happens in the walls of the air sacs. The blood that enters the wall of an air sac contains much dissolved carbon dioxide. The air in the air sac contains very little of this gas. Carbon dioxide thus passes from the blood into the air sac. At the same time there is much oxygen in the air sac and little in the blood. The lining of the air sac is always moist. You know that gases can dissolve in liquids. (See page 40.) The oxygen from the air dissolves in the moisture in the lining of the air sac. Then this moisture with its load of dissolved oxygen soaks through the walls of the capillaries, and the oxygen passes into the blood.

A moment after some air enters an air sac, it has lost some of its oxygen and has received carbon dioxide in place of the oxygen. The carbon dioxide must be removed from all the air sacs, and more oxygen must go in. Of course, it is your breathing, or *respiration,* that gets the used air out of the air sacs in your lungs and takes in fresh air. This is caused by the breathing movements made by the chest. Fresh air is brought into the lungs when you breathe in, or inhale, and used air is forced out when you breathe out, or exhale.

Some people think that all the oxygen is taken out of the air in the lungs and that what we breathe out is pure carbon dioxide. Table 14 shows that these ideas are incorrect. The air is mostly

TABLE 14. How the Air Is Changed in Our Lungs

| GASES IN THE AIR | AMOUNT IN AIR BREATHED IN | AMOUNT IN AIR BREATHED OUT |
|---|---|---|
| Nitrogen | 79.0% | 79.0% |
| Oxygen | 20.0 | 16.0 |
| Carbon dioxide | 0.04 | 4.0 |
| Other gases | 0.96 | 1.0 |
| Moisture | Variable amount | Almost saturated |

nitrogen. This is not used in the body; so its amount does not change as the air goes into and out of the lungs. But the air does change in three ways while it is in the lungs: (1) About one-fourth of the oxygen in the air goes into the blood. (2) An almost equal amount of carbon dioxide comes out of the blood into the air. (3) Moisture from the linings of the air passages and air sacs evaporates until the air is saturated.

HOW CAN YOU KEEP YOUR RESPIRATORY SYSTEM IN GOOD CONDITION? Like other parts of your body, the respiratory system really takes care of itself if you give it a fair chance. The breathing muscles are controlled automatically by nerve messages, so that you breathe at the correct rate to keep fresh air in the air sacs. The correct rate of breathing for a normal, healthy person of your age is about twenty-two breaths per minute. During illness it may become slower or more rapid.

Of course, you can breathe through either your nose or your mouth. But you should breathe through your nose because one way in which the respiratory system protects itself is by the structure of the nasal passages. The linings of the air passages are covered with microscopic living hairs, called *cilia*, that move back and forth. The movements of these cilia sweep dust and other useless materials up and out of the air passages.

The actual surface of the inner nose is very great because of the projection of the *turbinate bones* (Figure 131) which extend into the nasal passage. These bones are covered with a thin,

moist mucous membrane. As the air passes over this membrane, dust particles and germs are caught by the sticky surface. This membrane also contains many blood vessels, and the heat which escapes from them warms the air before it enters your lungs. You can easily understand why it is necessary to breathe through the nose. Mouth breathing not only looks bad, but it allows impurities in the air to enter the lungs, thus increasing the likelihood of disease.

Fig. 133. In certain kinds of work men and women wear or should wear masks to protect their lungs from dust. (Ewing Galloway photo)

If you have continued difficulty in breathing through the nose, you should ask a physician to examine the air passages. Sometimes they are deformed and partially closed by nose injuries suffered in childhood. In other cases they are almost entirely closed by large *adenoids*. Adenoids are masses of tissue at the back of the nasal passages (Figure 131). Their removal is a simple operation for a skilled physician.

The most important way to help your respiratory system is to keep yourself in good physical condition by getting enough rest, the right kind of food, fresh air, and a reasonable amount of exercise. Such diseases as colds, pneumonia, and tuberculosis, that attack the respiratory system, are much less likely to get started in persons who are in the best of condition. Of course, so far as possible you should also avoid the germs that attack the respiratory organs. You will learn more about how to avoid these disease germs in the next unit.

At all times we should breathe as little dust as possible because dust is likely to irritate the delicate linings of the air passages. Then germs can attack these linings more easily. Some kinds of dust, such as the dust from rock that contains quartz, cause serious disease in the lungs. People who must work continually in any kind of thick dust should protect themselves by wearing masks to strain the air.

*Self-Testing Exercises.* 1. Tell the story of an oxygen molecule that goes from an air sac into the blood. You may wish to draw a simple diagram to illustrate your story.

2. Do Exercise 1 for a carbon-dioxide molecule that comes back from a cell in the blood.

3. How is the air you exhale different from the air you inhale?

4. What do you think is the correct way to take care of your breathing organs?

*Problems to Solve.* 1. Fill in the story of the oxygen molecule in Self-Testing Exercise 1 from the time it entered the blood until it came back from the cell as a part of the carbon-dioxide molecule in Self-Testing Exercise 2.

2. Make as long a list as you can of the ways in which the lungs are fitted to do their work well.

3. Make a model to show how the diaphragm helps fill the lungs with air. Use a bell-jar with a neck as shown in Figure 134, or a large bottle without a bottom. Fit the neck with a stopper, glass tube, and thin rubber balloon. Use a piece of old inner-tire tube for the artificial diaphragm. Be sure to tie it so that no air can escape around the lower edge of the jar. Push in and pull out on the "diaphragm." What does the balloon do? Explain and compare the action of your model with that of the human chest and lungs.

4. How much air can you breathe out of your lungs? Fill a one-gallon glass jug with water and turn it upside down in a large pan that contains about three inches of water. Fill your lungs and breathe out through a rubber tube that extends up into the jug of water. Measure the amount of air you breathe into the jug. Compare your lung capacity with that of other members of your class.

FIG. 134

5. Do you think that you use more oxygen during one hour of the day or one hour of the night? Give a reason for your answer.

6. Why must adenoids and tonsils sometimes be removed?

## 3. How does the blood do its work for the body?

WHAT IS BLOOD? Ever since man began to think, he has connected blood and the beating of the heart with life. If the blood is lost or the heart stops beating, a man or an animal dies. Do you see now why these facts are true? It is because blood

carries food and oxygen to the cells and used materials away from them. And the heart must beat to keep the blood flowing. To know only these things about one's blood system does not satisfy an educated person. He wants to know how the heart pumps the blood, how the blood travels to every part of the body, and how it gets back to the heart.

First let us learn some of the more important facts about the blood. If you have a compound microscope, you can see for yourself what the main parts of the blood are.

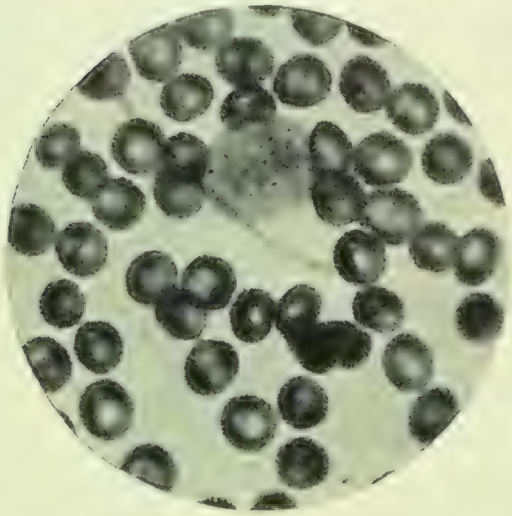


FIG. 135. Under the microscope the red-blood corpuscles look like this. In the upper centre is a white corpuscle.

*Experiment 41.* WHAT IS THE APPEARANCE OF BLOOD UNDER A MICROSCOPE? Have a very clean glass slide and cover-glass ready. Dip a clean, new needle in strong alcohol and rub a bit of the alcohol on the side of your thumb near the nail. The alcohol will kill any germs that are present. Prick the skin where you soaked it with alcohol and get a drop of blood to put on the slide. Or you may have another person get a drop in the same way from the lobe of your ear. Put a very small drop of the blood on the slide and spread it out very thin by putting the cover-glass on it.

Leave the cover-glass in place and look at the blood under the high power of the microscope. Look for a multitude of tiny yellowish disks. These are the *red corpuscles*, or red-blood cells. What is their real shape. Can you see that they are floating in a colorless liquid? If you can find a place where the blood is extremely thin on the slide, you may be able to see some irregular white-blood cells, or *white corpuscles*.

If you were successful in doing Experiment 41, you saw very, very many yellowish disks, called *red corpuscles*, floating in the blood. Each one of these is a single cell. When we see a great many of these together, they appear red. They are colored by a chemical compound, called *hemoglobin*. A single drop of blood

contains about twenty million of these cells. There are enough in the blood of a grown person to cover a surface equal to one half an acre. The main duty of the red-blood cells is to carry oxygen throughout the body. The hemoglobin in the cells combines easily with oxygen and gives the oxygen out again when the blood gets near the cells.

By looking a little more closely at a thin layer of blood under a microscope, we can find in it a smaller number of irregular, transparent cells. Some of these *white corpuscles* help protect the body from disease germs. The red and white cells make up about one-third of the blood. The remainder of the blood is mostly water in which are dissolved or suspended many different substances, such as salt, food, minerals for the formation of bones, waste materials from the cells, and chemicals that regulate the work of the body.

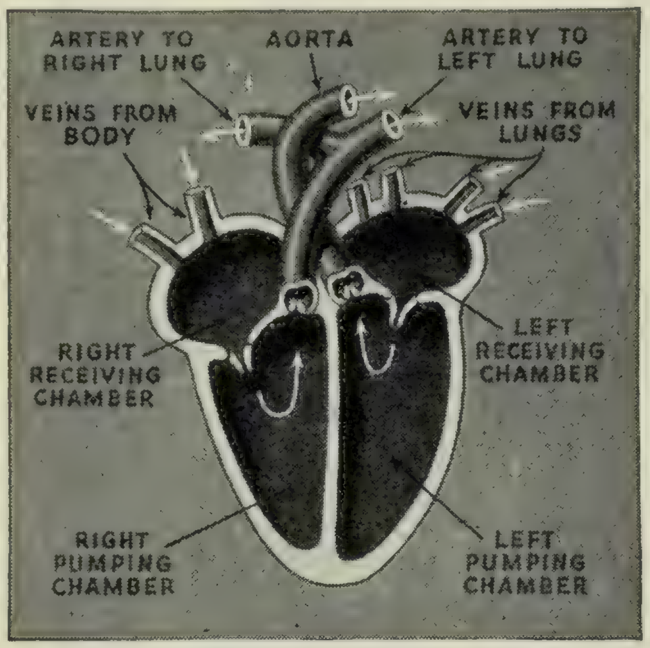



FIG. 136. Diagram of the human heart

Any nut would know!

HOW DOES THE BLOOD TRAVEL THROUGH THE BODY? Let us first get an idea of the heart and how it works. If you will look at Figure 136, you will see that the heart is separated into two main parts by a partition. Blood from one side of the heart cannot enter the other side of the heart. We usually think of the heart as a pump, but actually it is two pumps. The walls of the heart are made of thick, heavy muscles. When they contract, they squeeze blood out of the heart; when they relax, blood comes into the heart.

To find out how the blood does its work, let us start with the blood in the right side of the heart. When the heart muscles contract, this blood is forced through an *artery* into the lungs. Here the artery divides into capillaries. In the capillaries carbon dioxide passes out of the blood and oxygen passes in. Then the

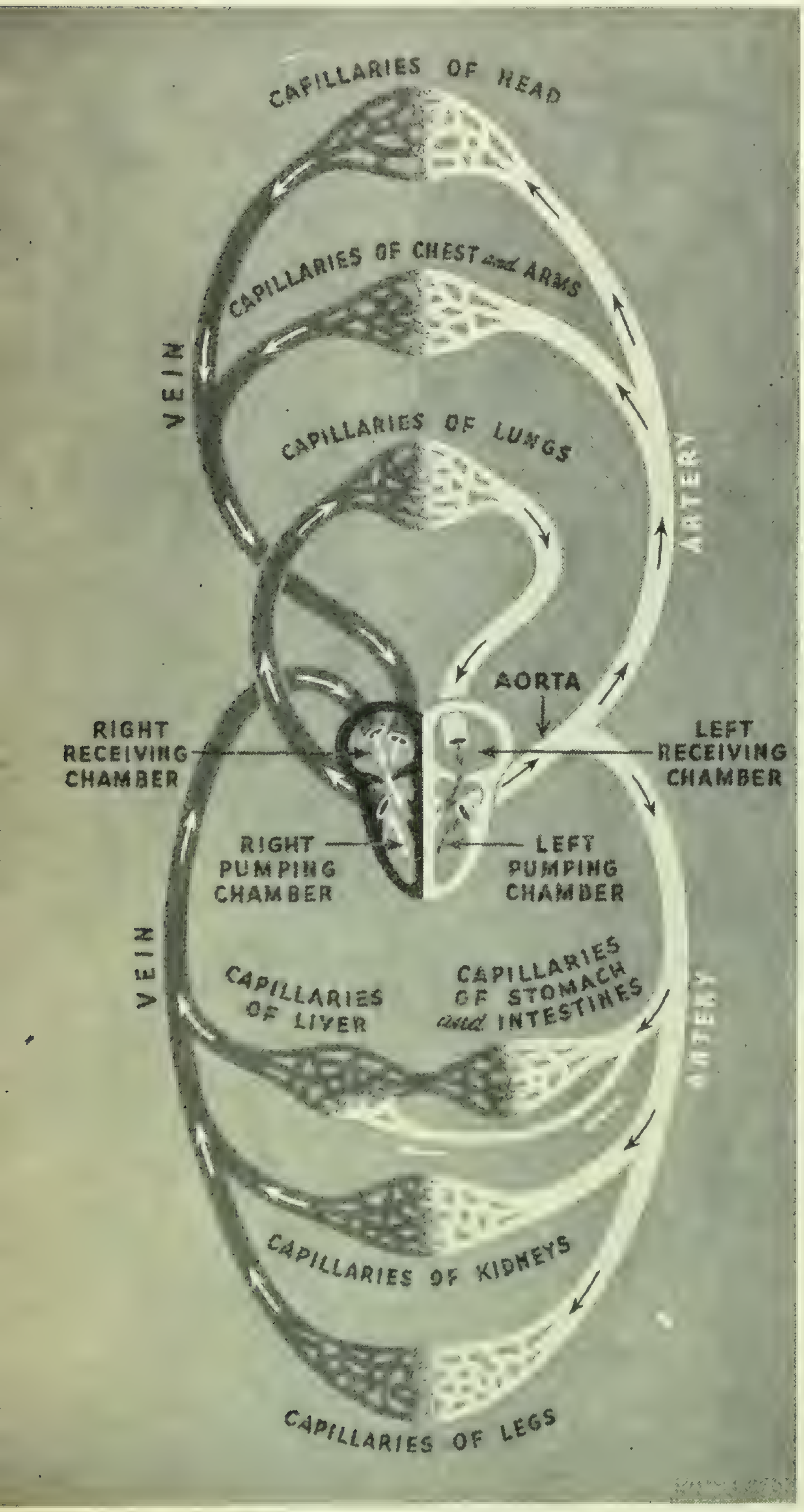



FIG. 137. A diagram of the way the blood travels through the body

capillaries unite to form larger and larger veins, and finally the blood enters the left side of the heart. When the heart muscles contract again, the blood is forced out of the left side of the heart into a large artery, the *aorta*. Figure 137 shows how the artery breaks up into smaller and smaller arteries that go to all parts of the body, and how the small arteries break up into capillaries.

In the capillaries some of the liquid part of the blood, the *plasma*, oozes through the walls into the spaces surrounding the cells. This blood is rich in food and oxygen and low in waste materials and carbon dioxide. Dissolved food and oxygen thus pass into the cells. Carbon dioxide and the broken-down cell materials, which are largely compounds of nitrogen, pass into the capillaries. The blood that leaves the cells thus has in it less food and oxygen and more carbon dioxide and nitrogen wastes. The capillaries unite to form veins, and the blood finally reaches the right side of the heart again. The time required for the complete circulation of the blood through the body is about one minute.

The blood still has one important work to do. It must get rid of the nitrogen wastes received from the cells. The blood cannot do this itself, but there are organs, the *kidneys*, which can. In Figure 138 you can see that a large artery passes into each of the kidneys, and a large vein passes out. In the kidneys these nitrogen wastes are taken out of the blood, sent to the bladder, and finally eliminated from the body in the urine.

You can see now what the blood does for the body. It brings food and oxygen to the cells. It takes away carbon dioxide and carries it to the lungs where it is given off and replaced with a supply of oxygen. It carries the nitrogen wastes to the kidneys where they are taken from the blood and finally passed out of the body. The blood is always moving and doing its part to keep us alive.

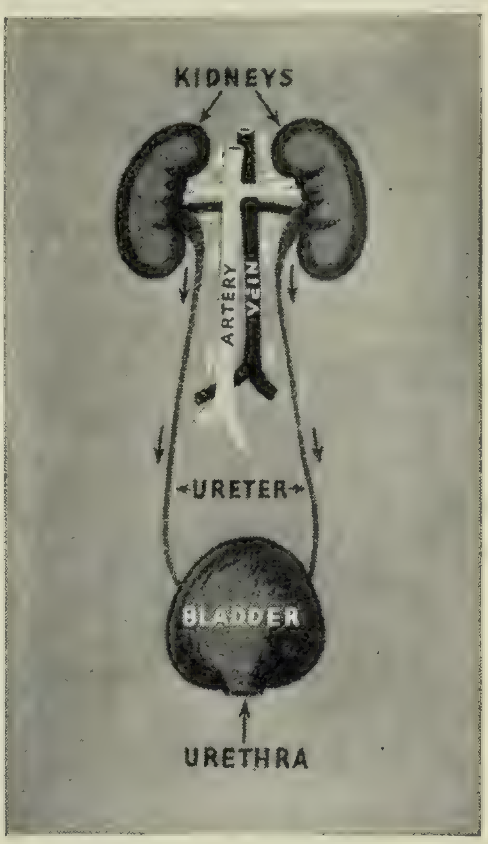



FIG. 138. The kidney system

Besides removing the nitrogen wastes from the blood, the kidneys have a large part in regulating the different materials in the blood. Whenever there is too much sugar, salt, or water in the blood, the kidneys remove the extra substance and thus help keep the correct amounts of these substances in the blood.

If kidney or bladder disease develops, it usually does so late in life when the body begins to "wear out." However, many doctors believe that we can help to avoid trouble by taking care of our kidneys. Drinking sufficient water (not less than four to six glasses a day) gives the kidneys an abundant amount in which to dissolve the waste materials. By keeping in good physical condition and by avoiding overeating and the excessive use of alcoholic drinks, we can protect our kidneys from overwork. Sometimes disease germs or their poisons injure the kidneys. One of the main reasons for having a doctor to care for us during illness is to avoid unnecessary damage to the kidneys.

*Self-Testing Exercises.* 1. Name the important parts of the circulatory system and tell what each one does.

2. What three important parts of the blood can be noticed under a microscope? Tell one thing that each part does.

3. Explain how the heart pumps blood.

4. Why are the kidneys a necessary part of the body?

*Problems to Solve.* 1. Under what circumstances would you expect the heart to pump more blood than usual? Find by feeling your pulse how many times your heart usually beats per minute. Then, when you think your heart is probably working harder than usual, count its beats again. What do you learn?

2. In how many places in your body can you feel a pulse? Make a list of the places. Under each of the places is an artery.

3. The walls of one ventricle of the heart are much thicker and heavier than the walls of the other ventricle. Do you think the thick-walled side pumps blood to the lungs or to other parts of the body? Give your reasons.

4. Why do you think the circulation of blood in the body is called a double circulation?

## ¶ 4. Why are exercise and rest necessary for your body?

To be in good shape

WHY DO WE GET TIRED? Everyone knows that at the end of the day he feels the need for rest and sleep. If you have been exercising strenuously, you are perhaps more tired than if you have been doing comparatively little muscular work. Even sitting at a desk all day results in a tired feeling. As you have learned, there is always a great deal of activity going on inside your body. The muscles of the heart and those that are concerned with breathing movements are in ceaseless activity. Other muscles that help hold your body erect must also do their duty.

Any work that the body carries on, either physical or mental, requires the expenditure of energy. This energy must come from the food you eat. In the process of oxidation, by which you get your energy, the cell materials are broken down, and waste products are formed. You have already seen that carbon dioxide is formed in this process. In addition, there are other waste products from the broken-down cells, and these tend to accumulate and to some extent poison the cells. It is the accumula-

FIG. 139. Outdoor exercise is important for growing boys and girls because it is an aid to their good health and proper growth. Exercise is necessary for the good health of most adults, too. (Century photo)

tion of these fatigue products in the tissues that gives you the feeling of being tired. To get rid of this tired feeling, you must get rid of these waste products.

HOW DOES EXERCISE HELP US GET RID OF WASTE MATERIALS? Exercise is particularly necessary for the brain worker. When you study hard, an increased supply of blood is sent to your brain, which decreases the quantity of blood in the stomach, muscles, and other parts of the body. This condition interferes with the proper removal of waste products from these parts of your body. Exercise, however, changes the demand in your body for blood. The blood is thus withdrawn from your brain and sent to your muscles, which are in need of more oxygen. The whole circulation of your body is thus changed by exercise. Another change in the circulation also takes place, as is shown in the following experiment.

*Experiment 42.* WHAT EFFECT DOES EXERCISE HAVE UPON THE RATE AT WHICH THE HEART BEATS? (*a*) When your heart pumps blood into the arteries, a wave of blood is sent through them. In order to count the number of heart beats per minute, it is only necessary to find a place where there is an artery close to the surface of the body. This can be found in the wrist or behind the ear. After you have been sitting still for some time, find out how many times your heart beats per minute by taking your *pulse*.

*b*) Take some light exercise and again count your pulse. How do the results obtained while you are quiet differ from those taken immediately after exercise?

When you exercise, your heart beats faster, and the blood circulates more rapidly. More oxygen and food are thus carried to the cells, and the wastes of the cells are removed more rapidly. These changes which take place as the result of exercise keep the whole circulatory system in good working order. With exercise, the rate of breathing increases, and you use your lungs to their fullest capacity. In this way you get enough oxygen to take care of the increased rate of blood flow and also to get rid of the waste materials formed as a result of the rapid oxidation of food and the destruction of body cells.

Exercise is also valuable in helping keep the muscles covering the abdomen strong and hard. These muscles help support the intestines, and by their movements they help push the food along and increase the circulation of the blood through the digestive organs. Proper exercise and toning up of these muscles help keep up regular habits of elimination from the bowels.

WHY ARE REST AND SLEEP NECESSARY? Rest and sleep are necessary to allow your body to recover from its daily activities. During the daytime the cells of your body are being broken down faster than they can be repaired, and waste materials accumulate more rapidly than they can be carried away. It is during the period of rest and sleep that the cells are rebuilt, that food materials are stored in the cells for future use, and that waste products are carried away by the blood. A rest of twenty to thirty minutes during the middle of the day is time well spent. It will raise your efficiency during the remainder of the day. Schools have recess periods for this reason. It is also very helpful to take a short rest before eating.

Even a change in occupation during the day is restful. Another kind of activity will make use of different muscle and nerve cells while the blood carries away the waste materials from overworked cells. However, there is no substitute for complete rest such as you get when you sleep. A man can go without food or water much longer than he can go without sleep. Nine or ten hours of sleep for a growing boy or girl are absolutely necessary. Failure to receive sufficient sleep will cut down your ability to do good work in school and will interfere with the healthy growth of your body.

*Self-Testing Exercises.* 1. Why do both physical exercise and mental exercise produce a feeling of tiredness? How do rest and sleep correct this condition?

2. Make a list of the changes that take place in your body when you exercise vigorously. For example, "*The heart beats more rapidly.*"

*Problems to Solve.* 1. Just standing still and doing nothing makes one tired. Explain.

2. It is not a good plan to exercise vigorously immediately after eating. Why?

## ¶ 5. How does bathing help the body?

WHAT EFFECT DOES BATHING HAVE UPON THE BODY? Everyone knows that we need to bathe to get rid of the dirt that collects on the skin. A clean skin is necessary for self-respect and the respect of others. Lack of visible dirt, however, does not necessarily mean that you are clean. Glands are constantly pouring certain fluid substances on your skin. The sweat glands pour perspiration, which contains certain waste materials in solution. The liquid part of the perspiration is absorbed by the underclothing and is evaporated. The solid materials remain on the skin and often clog the openings of the sweat glands, interfering with the proper regulation of the body temperature.

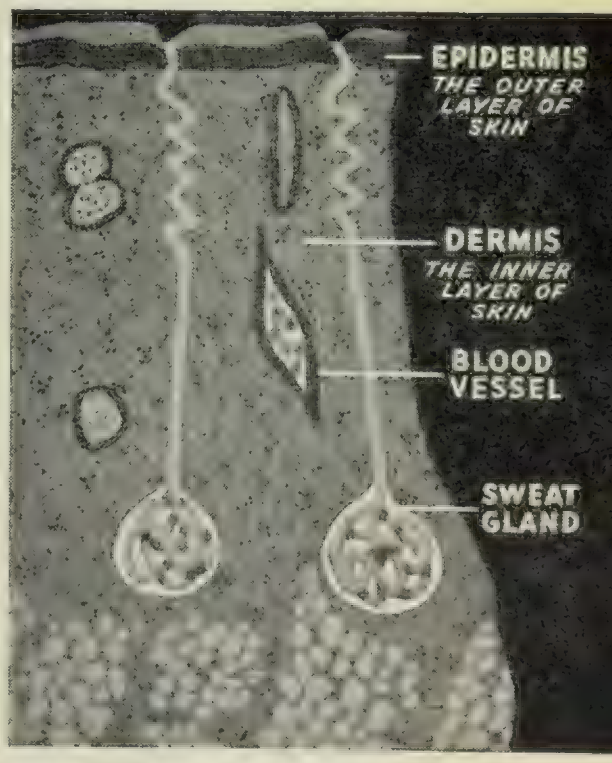



FIG. 140. A portion of human skin, showing sweat glands

Dead epidermis cells and wastes from the sweat glands, together with small particles of dirt, form good places for disease germs to grow. The clothing rubs these materials into the skin, which often results in an irritation, or even in some skin disease. Materials of this sort are often not visible. Yet it is just as important to remove them as it is to wash off the dirt that can be seen.

Bathing also has an important effect upon the temperature-regulating apparatus of the body. The temperature of the body is partially controlled by the blood vessels in this manner: When the blood vessels in the skin contract, the blood is sent to the

inner parts of the body. When these muscles relax, the blood vessels become larger, and more blood passes through the skin. In this way the body heat is automatically controlled, since, when a large quantity of blood flows through the skin, heat is lost; and when the blood is sent to the inner parts of the body, heat is saved. In order to keep the body at an even temperature, these changes in the size of the blood vessels must take place very rapidly in response to a given change of temperature outside the body.

A cold bath makes the blood vessels in the skin contract and drive the blood to the interior parts of the body. This is usually followed by a quick return of the blood to the skin. At this time vigorous rubbing with a coarse towel is necessary. The exercise of the muscles in rubbing and the return of the blood to the skin should make you feel warm and wide awake. The bath, therefore, exercises the muscles of the blood vessels and keeps them in good condition. It also stimulates your nervous system so that you are ready for action.

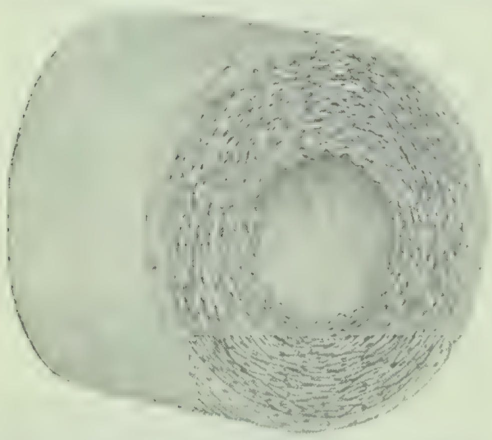


FIG. 141. A blood vessel, highly magnified to show the circular walls that regulate the flow of blood

Warm baths usually make the pores of the sweat glands open and thus increase the amount of perspiration upon the skin. When the skin is in this condition, you are very liable to "take cold." For this reason a warm bath should be followed by a short cold bath if you are going outdoors. A vigorous rubbing with a coarse towel is then helpful.

Both cold and warm baths are valuable to change the circulation of the blood within the body. In this way such baths help the body get rid of the products of fatigue; so they do for you somewhat the same thing that exercise does. A bath following vigorous exercise will often prevent lameness or soreness by removing the waste products from overworked muscles. Baths should never be taken immediately after meals, since they draw the blood away from the digestive organs and thus inter-

fere with digestion. A cold bath taken before breakfast is an aid to digestion and to the general nervous tone of the body. Warm baths should usually be taken just before going to bed.

*Self-Testing Exercise.* Write a short essay which will explain the effects of a cold bath and of a warm bath.

## ¶ 6. Why should we not use alcohol and tobacco?

THE FACTS THAT YOU WILL LEARN in this problem were obtained through scientific experimentation. The opinions that a great many people have about the effects of alcohol and tobacco are based upon prejudice rather than knowledge. The information in this problem is based upon known facts. Keep this in mind as you study this problem. You undoubtedly know individuals who use alcohol and tobacco and who apparently are not harmed. In the majority of cases, however, the harm is done to internal organs and thus is not visible to the eye. The effects of alcohol and tobacco can be determined only by the use of scientific apparatus.

WHAT EFFECT DOES ALCOHOL HAVE UPON THE BODY? If you keep yourself in good physical condition, you are making the body cells strong and healthy so that it is easier for them to resist the action of disease germs. A good physical condition also keeps the different organs in the body in good working order. Perhaps the most serious effect of alcohol upon the body is the lowering of the body's powers of resistance to disease. This makes it easier for the germs to attack the body and cause serious or fatal illness.

The *mortality records*, or death records, of large life-insurance companies furnish information for determining the effect of alcohol upon the resistance of the body. Many studies of this kind have been made. One company reports that 40 per cent of those who apply for life insurance are rejected for causes connected with the use of alcohol. Another company, which divides its policy-holders into "drinkers" and "non-drinkers," shows the following mortality in the two groups: Out of the number of deaths expected among the non-drinkers during a period of 40 years, only 71.54 per cent died. Of those who drank,


FIG. 142. This picture will help you understand what is meant by *reaction time.* Be sure that you can explain what this picture shows, and also what Figure 143 shows.

94 per cent died. This gives clear evidence that the use of alcohol shortens one's span of life.

Probably the most noticeable effect of alcohol upon the body is its action upon the blood vessels in the skin. A small amount of alcohol causes these blood vessels to enlarge, and hence the body loses heat rapidly. This loss of heat requires the body to oxidize more food to make good the loss. Thus the body is overworked. A second effect is this: Small quantities of alcohol have been found to increase the flow of the gastric juice, but this increase is always followed by a decrease in the flow after the effect of the alcohol has worn off. After long use of alcohol the gastric glands will not work unless they are stimulated by alcohol or some other stimulant. A third effect of alcohol is found in what it does to the muscle cells of the heart. These cells may be changed to fat, and thus the heart, which is really a pump, cannot force the blood through the body at the proper rate. This destruction of the vital cells and their replacement by fat take place in many parts of the body.

Many experiments have been carried on to discover the effect of alcohol upon a person's ability to work. One such experiment was carried on with a group of typesetters. The results showed that even one ounce of alcohol per day was sufficient to reduce by ten per cent the amount of work done. Another experiment determined the effect of alcohol upon a person's speed in responding to certain stimulations. In this experiment a person


FIG. 143. This picture shows how alcohol may cause an accident by slowing up the driver's reaction time. Why did the car travel 70 feet instead of 50 feet before the brakes were put on?

sits at a table with his finger on a telegraph key. A light is flashed, and he releases the key. The time between the signal and the release of the key is measured. This is called the *reaction time*. The experiment showed that the reaction time was shortened if the test was made immediately after the alcohol was taken; that is, the person acted more quickly. But if the test was made some time afterwards, the reaction time was very much longer than normal.

Reaction time is very important when a quick decision is needed, as, for example, in avoiding a collision with an automobile. To a person who has driven a car for a long time, the shifting of gears and the application of brakes are habits. The driver does not need to think about what he does. If another car or a person suddenly looms up in front of him, he automatically throws on the brakes. Now, of course, it takes a person a brief second of time to act after he sees the object. The time that it takes for him to react to the stimulus is called his reaction time. This time varies for different people, but for the average trained driver it is about three-fourths of a second.

You can see that a person's reaction time is very important in determining how quickly he can stop a car. Experiments have shown that alcohol makes a person's reaction time slower. In other words, it takes a second or more for an alcoholic person to react. In the meantime, the car is moving forward. A bad accident may take place because the car moved fifteen feet farther

before the driver could put on the brakes. A very large percentage of the accidents that occur at night are a direct result of the effect of alcohol upon the nervous system.

Accuracy is very important in many kinds of work. An experiment somewhat like the one described with typesetters indicates the effect of alcohol upon accuracy. The person is seated at a table with each hand placed on a telegraph key. If a white light appears, he is to press one key, and if a red light appears, he is to press the other key. Tests have shown that if a person drinks a small amount of alcohol, he will press the keys more rapidly than if no alcohol was taken, but the person tested will press the wrong key much more frequently than before. This effect of alcohol in making the individual more liable to quick and thoughtless judgments is one of the chief causes of the decrease in efficiency.

Human society through countless generations has built up standards of conduct and ideals of right and wrong. Individuals have also developed will power and the ability of self-restraint, so necessary when people must live together and get along peacefully with each other. These qualities are under the control of the brain. One of the first effects of alcohol is to dull or paralyze this nerve centre, and the individual loses the qualities which make him different from a savage. A person under the influence of alcohol will do and say things that he will not do or say when he is in full possession of his senses. In the occasional drinker, this dulling of the sense of right and wrong is only temporary, but there is always the grave danger that the use of alcohol will become a habit that cannot be broken. The result of such long-continued habit is a complete breaking down of the refinements which modern civilization has made, and moral degeneracy results.

WHAT EFFECT DOES TOBACCO HAVE UPON THE BODY? The effect of tobacco upon the human system has also been a subject of investigation by scientists. Their findings have shown that it is especially harmful to young people. Many countries have recognized this by passing laws that prohibit the sale of tobacco to children. Experiments have demonstrated that the average scholarship of tobacco-users in schools and colleges is lower than

that of students who do not use tobacco. Colleges and high schools have also found that the use of tobacco interferes with the efficiency of their athletes and have prohibited the use of tobacco by the members of their athletic teams. In general, experiments indicate that tobacco has at least three bad effects on the human body: (1) It interferes with the growth of the heart and produces a weakened condition known as "tobacco heart." (2) It interferes with the respiratory system by irritating the delicate membranes of the throat and lungs. (3) It interferes with the action of the digestive juices. These findings indicate that the tobacco habit is decidedly injurious.

*Self-Testing Exercises.* 1. What is meant by reaction time?

2. Why is a person's reaction time a very important part of his activities?

3. In what ways does alcohol affect the body?

4. In what way does tobacco affect the body?

*Problems to Solve.* 1. In what situations would a quick reaction time be advantageous?

2. How might slow reaction time be disadvantageous in athletics?

FIG. 144. Blood drained from a large vein in this girl's arm will be given to a person who has lost blood in an accident. (Black Star photo)

## ¶7. What can you do in case of accident?

VERY FEW PEOPLE pass through life without sometime needing a knowledge of first aid to the injured or sick. Of course, a doctor is necessary in a great many cases, but doctors are not always on the spot; and in most instances a great deal can be done before the doctor arrives. The best way to remember how to give first aid is through actual practice. The method used in caring for cut arteries and in securing artificial respiration should be practised with some other pupil. The other methods should

be practised when the occasion arises. The next time you or any of your family have cuts, sprains, foreign bodies in the eye, or burns, try the methods of first aid described in this problem.

How should cuts and scratches be treated? Perhaps the simplest case of first aid is presented by injuries due to cuts or scratches. These are not often dangerous, but sometimes the smallest cut or scratch may cause death from blood poisoning. For this reason such wounds should not be neglected. Bleeding helps wash out any germs that might *infect* them. Do not touch the wound with your hand, mouth, or clothing. It is safer not to clean the wound with soap and water or to use a strong antiseptic on it. If the wound is then covered with a piece of antiseptic gauze, the danger of infection will be reduced. In case the wound is serious, the clothing should be removed from around it, and the wound exposed to the air. If the wound is bleeding freely, it should be bandaged tightly with antiseptic gauze, and a doctor should be called at once.

In some cases the blood may come from a wound in jets or spurts. This shows that an artery has been cut, and it is necessary to stop the blood flow immediately. Pressure, therefore, should be applied to the artery between the wound and the heart. Use a pad of antiseptic gauze or a clean handkerchief. If the injury is in an arm or a leg, you may have to use a tourniquet (Figure 145). This can be made by tying a knot in a handkerchief and laying it over the artery. Insert a stick through the bandage and twist it so that the knot will press on the artery and stop the bleeding. Loosen the bandage occasionally to see if the bleeding has stopped, because if it is kept tight too long, it will cause trouble.

Fig. 145. This shows how to use a tourniquet to stop bleeding from a wound in the wrist.

How should bruises and sprains be treated? In a bruise the tissue beneath the skin is crushed, causing internal bleeding. Bruises should be treated by placing something cold on

FIG. 146. This is the correct position for beginning *artificial respiration*. (American Red Cross photos)

FIG. 147. This is the correct position at the time of applying pressure.

them. A cloth which has been wrung out in cold water is usually sufficient. In cases of sprain (injury to the ligaments), cold applications are also desirable. Severe sprains should be treated by a physician.

HOW CAN YOU GIVE "FIRST AID" IN DROWNING, SUFFOCATION, AND ELECTRIC SHOCK? The body must always be able to take in good air and get rid of bad air. When the body cannot do this, we have *suffocation*. If a person has been under water for some time, or in a room containing poisonous gases, or has had a severe electric shock, his breathing stops. Such a person frequently can be brought back to consciousness by using *artificial respiration* to help him in breathing. A Standard Red Cross textbook on *First Aid and Relief Columns* gives the following directions:

The patient is laid on the ground, face down. The arms may be stretched out at full length over his head, or one arm may be bent so that the forehead rests upon it. In either case the face must be placed slightly to one side so that the ground will not block off the air from nose and mouth. As soon as the patient is in proper position, the operator kneels at one side, or astride the body, but without resting his weight upon it (Figure 146). The palms of his hands are placed on the short ribs across the small of the back, with the thumbs nearly together. The operator, by letting his weight fall on his wrists and by bending his body forward, decreases the size of the chest, and the air is expelled from

the lungs. The pressure is then released by the operator swinging backward; the elastic chest springs out to its original size, and the air is drawn into the lungs. The movement is at the rate of twelve to fourteen a minute. It is wise to time the rate with a watch. Whatever the method of artificial respiration used, it should be kept up for at least an hour and a half. Sometimes artificial respiration is continued for four hours, if necessary.

HOW ARE INJURIES FROM HEAT AND COLD TREATED? Another class of injuries which need special attention are those due to heat and cold, such as burns and scalds, sunstroke, and frostbite. Burns and scalds should be treated by excluding the air. Vaseline, olive oil, cream, or a thin paste made of baking-soda can be used. The burn should then be lightly bandaged. In all cases of severe burns a doctor is necessary. In cases of sunstroke a doctor should be sent for at once, and in the meantime the patient should be treated by rubbing cold water or ice over the face, chest, neck, and armpits. The object of such treatment is to reduce the body temperature. In cases of frostbite the frozen part should be brought back to normal temperature slowly. This may be done by rubbing the part with a dry towel and then letting it gradually thaw out in cool air or cold water.

HOW ARE FOREIGN BODIES REMOVED FROM THE [redacted]? EARTH Sand, cinders, or particles of dust in the eye cause a great deal of pain. In removing them, the first thing to remember is not to rub the eye, because such rubbing may injure some of the delicate parts. If the eye is closed and the tears are allowed to accumulate, the object will frequently be washed out. Or the upper lid may be pulled down over the lower several times. Sometimes, if the nostril on the opposite side is closed and the patient blows his nose very hard, the desired result will be secured. If this does not remove the object, have the patient look up, press the lower lid down, and examine the lower surface. If the object is seen, wipe it off with the corner of a clean handkerchief or, better still, with a piece of moist cotton wrapped around a match stick. To remove objects under the upper lid, grasp the lashes of the upper lid gently between the thumb and forefinger, have the patient look down, and pull the upper lid forward and downward over the lower lid. If the object is imbedded, see a doctor immediately.

*Self-Testing Exercise.* Make a list of the materials you need for a first-aid kit. Prepare a series of labels for each material, stating what it is to be used for and the method of using it.

*Problem to Solve.* If you are a Boy Scout, a Girl Guide, or a Camp Fire Girl, you might demonstrate several first-aid practices before the class. For example, you could show the class how to use a tourniquet.

## Looking Back at Unit 7

1. Use about two pages to tell the really important ideas about how the body works. Choose your ideas carefully. Then write them down in a connected way, so that a person reading your summary can understand about the body.

2. Show in some way that you know the meaning of each of the following terms.

| | | | |
|---|---|---|---|
| *vein* | *cartilage* | *reaction time* | *artery* |
| *tendon* | *ligament* | *bronchial tubes* | *corpuscle* |
| *vertebra* | *tourniquet* | *hemoglobin* | *cilia* |
| *larynx* | *joint* | *respiration* | *pulse* |
| *plasma* | *trachea* | *exhale* | *aorta* |

## Additional Exercises

1. Read in reference books about how different animals, such as fish and insects, get oxygen.

2. Determine your rate of breathing per minute (*a*) while standing, (*b*) while lying down, (*c*) after strenuous exercise. How do you account for any differences in the rates?

3. What information does a physician obtain when he feels your pulse?

4. Shake up a quart of clear limewater with air. Then put a goldfish in the water. How does the water change? Explain what happens.

5. Find in reference books what the ductless, or *endocrine*, glands do for the body. Some of these glands are the thyroid gland, adrenal glands, and pancreas.

6. Look in the *World Almanac* or similar book of facts for the most common causes of death. Which set of organs seems to wear out most often? (Cancer is not a disease of any one set of organs.)

7. Compare the working of the heart with the working of a water pump. Refer to pages 219-220.

8. Plan and try an experiment to find out if a candle will burn in the air you breathe out.

9. Read in reference books to find what William Harvey discovered about the blood and how he discovered it.

10. A tourniquet is often used in treating snake bites. It is applied between the wound and the heart. Explain.

11. A pulmotor is often used in cases of drowning and suffocation. Explain the use of the pulmotor for this purpose.

12. Make a set of health rules which you will try to follow. Consider all the points you have learned in this unit.

## Books to Read

Andress, J. M., and Evans, W. A. *Practical Health Series*, Vol. 2. Ginn, 1933.

Baruch, Dorothy, and Reiss, Oscar. *My Body and How it Works*. Harper, 1934.

Bush, G. L., Ptacek, T. W., and Kovats, John. *Safety for Myself and Others*. American, 1937.

Cole, N. B., and Ernst, C. H. *First Aid for Boys*. Appleton-Century, 1931.

Cottler, Joseph, and Jaffe, Haym. *Heroes of Science* (pages 93-101). Little, 1932.

Downing, E. A. *Science in the Service of Health* (pages 259-281). Longmans, 1930.

Fishbein, M. *The Human Body and Its Care*. American Library Association, 1929.

Haggard, H. W. *What You Should Know about Health and Disease* (pages 253-264). Harper, 1928.

Huxley, J. S., and Andrade, E. N. da C. *Simple Science* (pages 179-278). Harper, 1935.

Turner, C. E. *Physiology and Health*. Heath, 1935.

TO HELP YOUR BODY FIGHT DISEASE, scientists are constantly forging new weapons. One of these weapons is the growing family of "sulfa" drugs that began with sulfanilamide not many years ago. In the form of pills, powders, and ointments these drugs are used to check infections caused by certain kinds of germs. Here in a laboratory a scientist is grinding up a sample of a "sulfa" drug so that he can test its purity and strength. In this unit you will learn many other things that scientists have done and are doing in the fight against disease. (INS photo)

# UNIT 8

# How Can You Help Your Body Fight Disease?

## Looking Ahead to Unit 8

Did you ever have someone say to you, "Good-morning. How do you feel today?" Perhaps you replied, "Good-morning. I feel like a *million dollars*." That was a slang way of saying that your body was working well. Probably you did feel like a million dollars so far as your health was concerned. Certainly no one would take a million dollars for his health. All the money in the world would be of little value to a person if he were sick all of the time.

People have done, and still do, many strange things to try to keep their health or to regain it if they have lost it. In times of long ago people were so ignorant of how the human body works that they did not know what made them sick or what to do to get well. Suppose you were a member of some very primitive tribe of people and you became ill. How would the tribal witch-doctor try to cure you? There might be ceremonial dances with the loud beating of tom-toms to scare away the evil spirits that were supposed to cause the disease. If this failed, the witch-doctor might give you a necklace made of animal's teeth. He would tell you that this charm, if worn, would drive the disease away. He might even sew an animal's tooth, some burned feathers, a few bones, and some ashes into a sack made of frog skin. He would tell you to wear this as a protection against the disease. Of course, you would not be willing to trust these foolish kinds of remedies.

However, people today do things that are just as foolish. They buy and use treatments that are worthless or even harmful. Look through certain magazines, and you will see many such false

Fig. 148

Fig. 149

The Indian medicine-man (Fig. 148) is treating a patient by holding an apple stuck full of feathers on his neck. The other medicine-man (Fig. 149) is selling a patent medicine, which is useless and perhaps harmful. Instead of these superstitious remedies and patent medicines reliable doctors use treatments that scientists have proved to be helpful in fighting disease. (Ewing Galloway photo)

cures advertised. Some of them claim to cure gallstones; others, stomach and intestinal diseases; and some of the most extreme even claim to cure the dreaded disease, cancer. These advertisements are harmful in two ways: (1) They take the patient's money and give him no real benefit in return; and (2) they prevent or delay the getting of advice from some honest, well-trained doctor. Strangely enough, some people take such "quack" treatments and actually get well. But they do not get well because of these so-called cures; they get well in spite of them. Their bodies are strong enough to fight the diseases and overcome the "treatment," too.

For centuries men lived in ignorance of the causes of those diseases that were most common. Often such diseases spread so rapidly that thousands of people died in a few weeks or months, and men were helpless to stop them. Even today serious *epidemics* occur. The great difficulty in fighting certain diseases is that, even today, little is known about what causes them and the ways in which they spread. This is true of influenza and infantile paralysis. However, the great loss of life from epidemics has become less and less in the civilized parts of the world as scientists have learned more about disease germs and the ways of guarding

against them and as people have learned to follow the advice of scientifically trained doctors and health authorities.

In spite of all the precautions we take, germs do reach our bodies and get inside them. What are these disease germs? How do they grow in the body? How do they cause the weakness and fever, inflammation and pain that tell us we are sick? In most cases the body wins the fight, finally killing off the germs and repairing, as well as possible, the damage which has been done. How is the body able to do this? And how can we help the body defend itself against such deadly enemies? Knowing the answers to these problems, we shall be better able to coöperate intelligently with our bodies, with our doctors, and with our community in the war on germs.

## ❡ 1. What are disease germs?

HOW WERE DISEASE GERMS DISCOVERED? Almost two hundred and fifty years ago, Anton van Leeuwenhoek, a Dutch scientist, discovered plants and animals so small that no one had ever dreamed they existed. They could be seen only through a microscope, and in those days the microscope was a new instrument. In Unit 5 you learned something about these tiny plants and animals. When van Leeuwenhoek discovered these tiny living things, man had made the first great step in learning the causes of many serious diseases and the methods of fighting these diseases.

Eighty years after Leeuwenhoek's time another wonderful discovery was made by Lazaro Spallanzani, an Italian scientist. He actually saw one of these tiny one-celled *organisms* divide into two organisms. Then he saw the two organisms divide into four, four into eight, etc. In this way he learned that these tiny living things can multiply and produce countless other living things like themselves. At first people believed that these tiny things grew spontaneously from the decaying material, the water, and the slime where they were most often found. Even when Spallanzani told what he had seen, many people would not believe him. But he was right, and when he discovered how these tiny organisms really make other organisms like themselves, the second great step had been taken in finding the cause and cure of many diseases.

Fig. 150

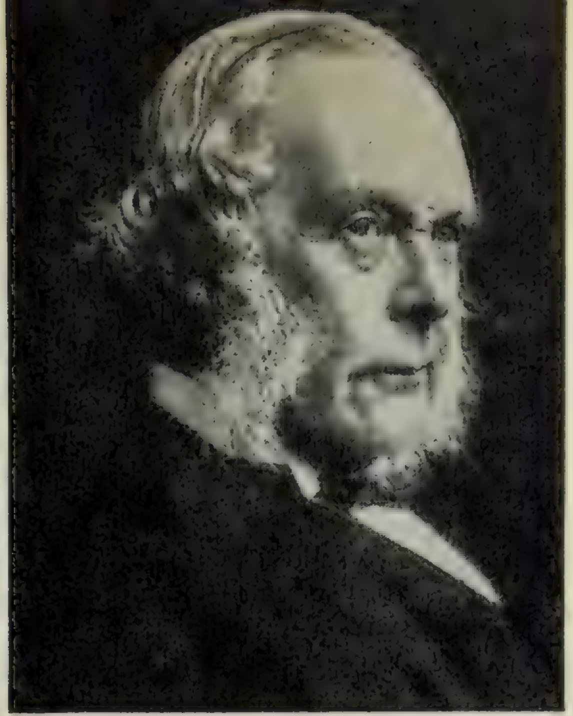


Fig. 151

Louis Pasteur, shown here in his laboratory, and Joseph Lister are two of the great scientists without whose discoveries we would not know how to fight disease germs successfully.

Then, about 100 years later, during a period of twenty memorable years from 1860-1880, three great men of Europe, Louis Pasteur, a Frenchman, Robert Koch, a German, and Joseph Lister, a famous British surgeon, proved conclusively that germs, or *microbes*, were the cause of certain diseases. When this fact was proved beyond the shadow of a doubt, medical scientists saw that the problems of preventing and curing many kinds of disease were: (1) to keep these tiny living things from getting into the body, (2) to know how to kill germs without harming the body, or (3) to help the body kill germs and repair itself. In this unit you will learn the important things about how medical scientists have solved these problems and how you can help solve them.

Of course, not all diseases are caused by germs. When some organ of the body fails to do its work, we say the disease is *organic*. Heart trouble, caused by the improper working of the heart, is an organic disease. The kidneys and the liver may also fail to do their work properly because they are injured in some way. However, in this unit you will study chiefly the diseases that are caused by germs, that is, the *infectious* diseases.

*Self-Testing Exercises.* 1. Explain what is meant by a disease germ.

2. What is the difference between organic diseases and infectious diseases? Give an example of each kind of disease.

3. What two discoveries did man have to make before he could learn how to fight infectious diseases?

FIG. 152. In all parts of the world men and women called *bacteriologists* spend their lives searching for bacteria that are still unknown and for methods of fighting those that are known. You may find it interesting to watch in newspapers and magazines for news of important discoveries about disease germs.

WHAT KINDS OF GERMS ARE THERE? Do you know that many tiny plants actually live in our bodies? Some of these organisms do us little or no harm, while others cause serious diseases. Many of the microscopic plants that cause diseases are *bacteria*. As you know, bacteria are one-celled plants of various sizes and shapes. Each tiny plant, or *bacterium*, is so small that from 5000 to 50,000 of them are required to make a row one inch long. Some bacteria are so small that a million of them could be placed on top of an ordinary pin-head. Yet, if the conditions are right, a single one of these bacteria may grow and make more bacteria by splitting in two until there are enough of them to kill a man or even an army of men.

Many bacteria help man by enriching the soil, by causing the decay of dead plants and animals, by souring milk to make cheese, and by doing many other beneficial things. It has even been said by scientists that man could not live on the earth if it were not for the work of these tiny plants. Many other kinds of bacteria seem to be neither useful nor harmful. The disease-producing, or *pathogenic*, bacteria are of the most direct importance to us. *Bacteriologists* have proved many times that such diseases as diphtheria, tuberculosis, and typhoid fever are caused by certain kinds of bacteria. Such bacteria make up one group of disease germs.

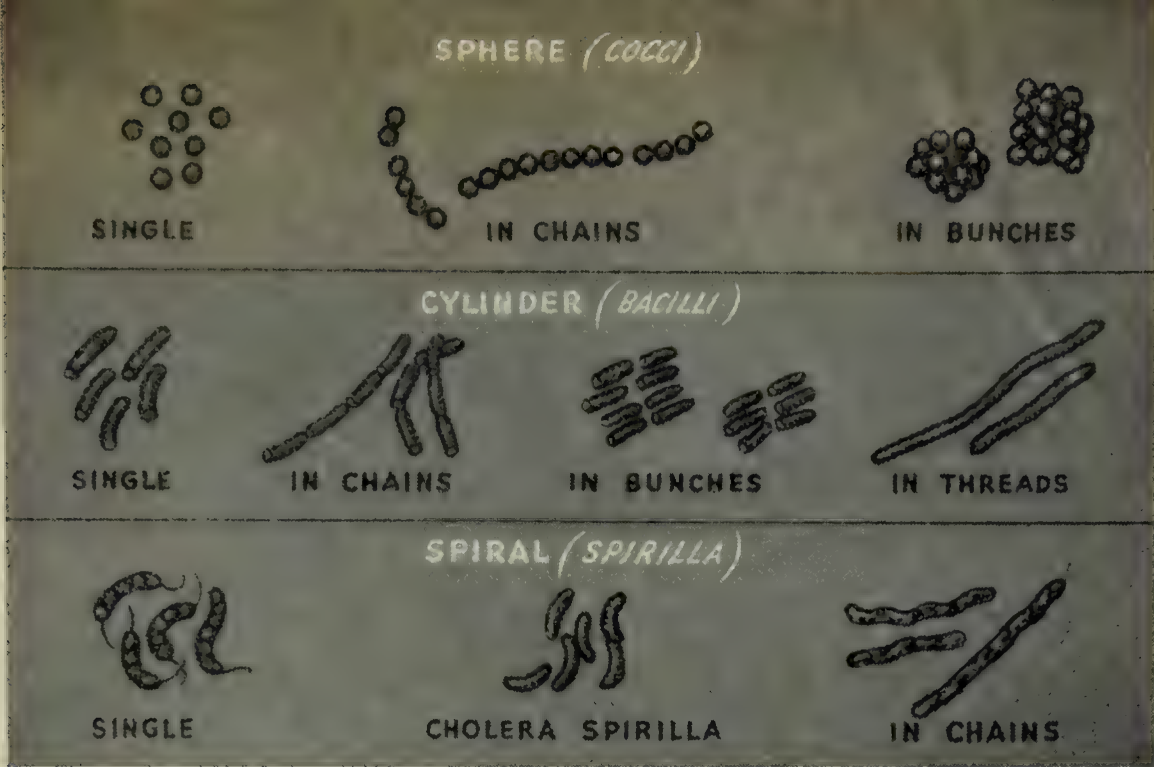



FIG. 153. The three general groups of bacteria. When cocci are in chains (top centre), they are known as *streptococci*.

There are thousands of different kinds of bacteria; so their classification is a rather difficult matter even for the bacteriologist. However, most bacteria may be recognized by the effects that they produce while they are growing and by their shapes. Three groups of bacteria are commonly recognized.

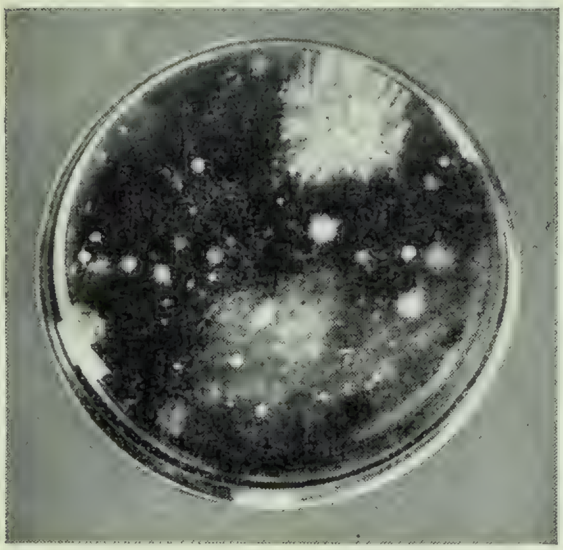
Suppose that a bacteriologist is letting you examine some of these plants under a very powerful microscope. You find some tiny, ball-shaped cells. These cells may be separate from each other, or they may be in long chains or in bunches (Figure 153). "Those are cocci," says the bacteriologist. "Scarlet fever and pneumonia are caused by the coccus type of bacteria."

You put another slide under the microscope and focus the instrument. This time you see many peculiar cylinder-shaped cells. Some are attached end to end like links of sausages; others are grouped in small bunches or masses. "These are not cocci, for they are shaped differently," you say.

"No," the bacteriologist tells you, "they are *bacilli*. Perhaps you have known people who have had typhoid fever or tuberculosis. The germs of these diseases are of the *bacillus* type."

You examine another slide under the microscope. This time you see corkscrew-shaped cells. Some are by themselves, and others are joined together to make something that looks like a spiral chain. "These bacteria seem to be shaped like springs or spirals. They must be another kind," you say.

"They are another kind," answers your friend. "You already



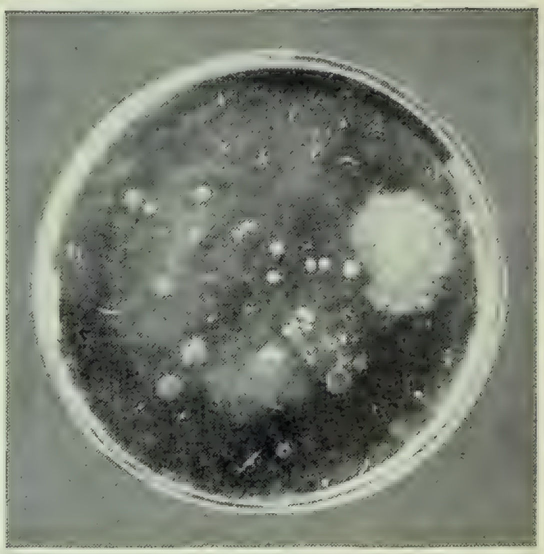


FIG. 154. The culture dish at the left was uncovered for twenty minutes. The large spot is a mold growth; the small spots are colonies of bacteria. The other culture dish also shows spots of bacteria that grew after fingers had been rubbed across the surface of the gelatin.

have the name, *spirilla,* from their spiral shape. The disease cholera is caused by the *spirillum* type of bacteria."

Perhaps you would like to grow some bacteria so that you can examine them to see what they are really like.

*Experiment 43.* WHERE ARE BACTERIA FOUND? Boil six shallow dishes with tight covers for half an hour to sterilize them. While the dishes are boiling, mix about five ounces of unflavored gelatin in a quart of water. Add a pinch of salt and one-half ounce of beef extract or sugar. Heat the mixture until the gelatin is dissolved.

Pour enough of the gelatin mixture into each dish to cover the bottom. Then set the covered dishes in a covered steamer or a steam sterilizer. Keep them in live steam for an hour. Then let them cool. When the gelatin has hardened, treat the six dishes as follows:

*a*) Leave one dish open to the air for about fifteen minutes. It is best to do this after the room has just been swept and there is dust in the air. Then cover the dish.

*b*) Scrape around your teeth with a toothpick and rub the toothpick over the surface of the gelatin in another dish; then cover it. Label each dish so that they will not become mixed.

*c*) Put a few drops of unclean milk on the gelatin in another dish; then cover the dish.

*d*) Rub your fingers across the surface of a dish; then cover.

*e*) Keep another dish of clean gelatin tightly closed.

Keep the dishes at room temperature (or slightly warmer) for

several days. Watch for pink, yellow, or white spots on the gelatin. These will be *colonies* of bacteria. (Remember that a single bacterium is too small to be seen without a microscope.) Explain what happens in each case. If your work was carefully done, colonies of bacteria did not appear in dish e. Why not?

In Experiment 43 bacteria probably grew in each of the dishes except the one that was kept tightly closed. This might lead you to believe that bacteria are almost everywhere. And such is the case. Scientists have carried dishes of gelatin up into the stratosphere, to the tops of highest mountains, and deep into mines. In every place that they have tested they have found bacteria present.

But bacteria are not the only plants that cause diseases. Certain kinds of *yeasts*, which are one-celled plants, may get into broken places in the skin and cause sores. Tiny mold-like plants cause a skin disease known as "athlete's foot." Parts of these small plants break off from plants that are on the foot of a person who has the disease. Then, when another person steps upon these plants, they lodge in moist places upon the skin of that person's foot and grow, causing him to develop the disease.

Some kinds of one-celled animals may get into the body and cause diseases. But there are not nearly so many different kinds of one-celled animal germs as there are one-celled plant germs. However, they have many different shapes, and they affect different parts of the body. Amebic dysentery, malarial fever, and African sleeping-sickness are diseases known to be caused by certain one-celled animals. When animal germs get into the body, they multiply in different ways to produce more germs. Each germ may divide into two parts, as bacteria do; or each germ may divide into many smaller parts, each part being able to grow into a new germ. Trichina and other worms also cause diseases.

Some diseases, such as common colds, influenza, smallpox, mumps, and measles, have puzzled scientists greatly. They act like germ diseases. They are easily spread from one person to another, and they make us sick in a similar manner. But the germs that cause these diseases have never been found. When discharges from the bodies of persons suffering with these diseases

are filtered, no germs can be found in the filtered liquids. Yet we know that these liquids cause diseases in other people.

What, then, really causes these diseases? Scientists know that some of them are caused by extremely small materials called *viruses* (Figure 155). A virus can pass from one person to another much as germs do. Scientists have discovered ways of preventing some of these virus diseases, such as smallpox and rabies. For others, such as common colds and infantile paralysis, they have been able to do little.

FIG. 155. Influenza virus magnified 30,000 times. (Duke photo)

*Self-Testing Exercises.* 1. Are all bacteria harmful? Explain.

2. (*a*) Scarlet fever is caused by *streptococcus* germs. From their name, what shape do you think they have?

*b*) Leeuwenhoek wrote a paper in 1683, describing a tiny living thing that he thought was an animal. Later, other scientists found it living commonly in saliva. They gave it the name *Spirillum sputigenum*. What was its shape?

3. Which of these statements is correct? Explain your answer.

*a*) *All bacterial diseases are germ diseases.*

*b*) *All germ diseases are bacterial diseases.*

4. Divide the names of the diseases below into three lists according to their causes: *Plant Germs, Animal Germs, Probably Viruses.*

| | | |
|---|---|---|
| common colds | scarlet fever | tuberculosis |
| malaria | pneumonia | measles |
| influenza | sleeping-sickness | smallpox |
| mumps | typhoid fever | athlete's foot |
| diphtheria | infantile paralysis | cholera |

*Problems to Solve.* 1. Frequently you read or hear that a person is ill with a streptococcic infection. What kind of germs would cause this illness?

2. A common kind of pneumonia is caused by a germ called pneumococcus. What kind of germ is it?

3. Some many-celled animals cause diseases. Find out about the hookworm disease, tapeworms, and trichinosis.

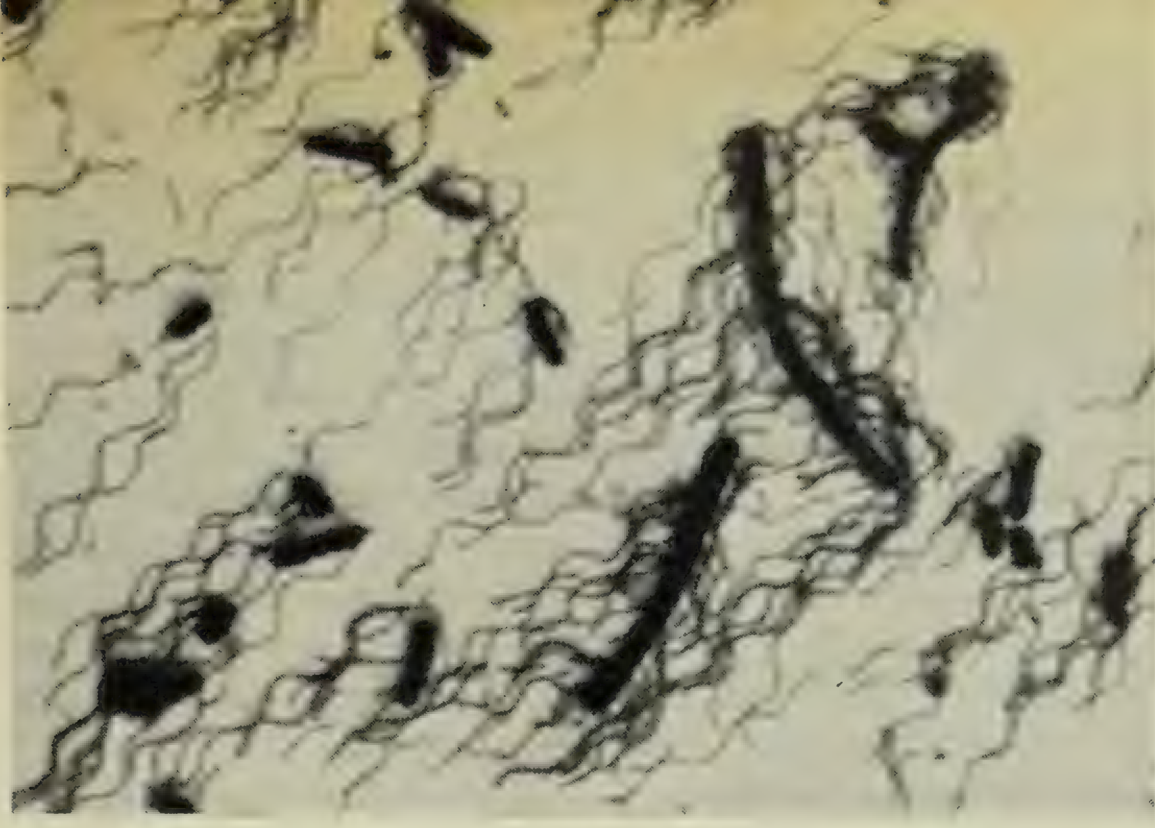


FIG. 156. These typhoid bacilli have been magnified several thousand times, and you can see the long whip-like *flagella* that enable them to move rapidly about in a liquid. (©General Biological Supply House photo)

## 2. How do germs make us sick?

HOW DO YOU FEEL just before you have to go to bed with a disease—scarlet fever, for example? You feel tired, you cannot eat, your throat is sore, and usually you have fever. What do germs do to your body to make you feel this way? Germs, like other living things, need food, moisture, and warmth in order to thrive. But unlike most living things, they need darkness instead of sunlight. When germs get inside the body, they find all of these conditions and begin to grow at once. And how fast they multiply! In about fifteen minutes a single bacterium divides, and there are two bacteria. In fifteen minutes more these two have divided, and there are four; in another fifteen minutes there are eight, and so on. In less than a day at this rate there would be more bacteria than there are people in our country.

Fortunately for us, germs cannot continue to multiply at this rate of speed for very long. Lack of food and the poisons they produce help to hold them in check. Then, too, when the body is in good condition, it fights them, as you will learn later.

Once germs are in the body, they begin to seek the part of the body best suited to their growth. Tuberculosis and pneumonia germs grow best in the lungs. Dysentery and typhoid germs grow best in the intestines. Malaria germs prefer red-blood cells. Some

kinds of germs, such as those that cause blood poisoning and lockjaw, seem to grow well in any part of the body.

When germs reach the part of the body where they can grow best, they immediately begin to do their damage. As you know, the body is made of millions of tiny cells. Germs must have food in order to live; so they get their food from the cells of the body. This destroys great numbers of cells. Of course, the body builds new cells to take the place of those destroyed by the germs. But this work of building the new cells puts an extra strain on the body, because the body must make new cells in addition to carrying on the rest of its work.

Have you ever seen a "boil" on someone's skin? How did it look? Usually the skin is red and "angry-looking," or *inflamed*. Also, the area around it is swollen. A boil is not a very pleasant thing to have because it is very painful. How did the germs cause a boil to happen? As germs grow, they give off poisonous substances known as *toxins*. These toxins cause the redness and soreness around the boil. A boil is not usually dangerous because the poisoning is limited to a small area. The boil soon bursts and lets out masses of white or yellow material known as *pus*. This pus contains masses of germs, dead body cells, and the white corpuscles of the blood that helped destroy the germs.

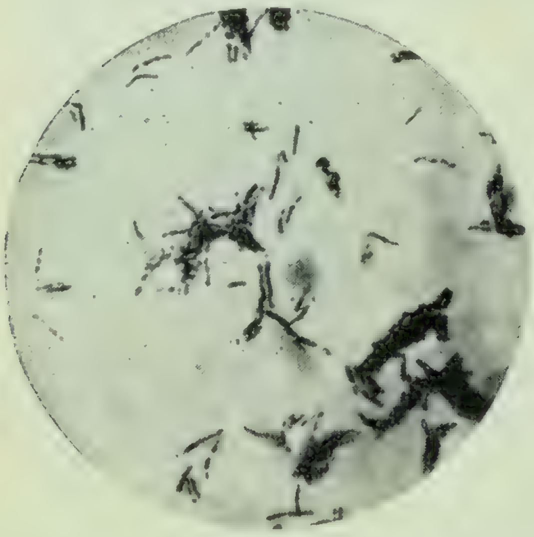


FIG. 157. Tuberculosis germs magnified thousands of times (©General Biological Supply House)

Other diseases may not be so simple as boils. Germs may make toxins that are spread to many parts of the body. For example, diphtheria germs growing in the throat give off a toxin that enters the blood and poisons the heart, nerves, and kidneys. Sometimes these poisons may injure the organs of the body permanently. In this way an infectious disease may cause an organic disease. Perhaps you have had your tonsils removed. Why was this necessary? Some kinds of germs are able to live and grow in certain

parts of the body, such as the tonsils, the teeth, and the *sinuses*. The sinuses are small pockets in the bones of the head. These germs do not make us sick immediately, but they furnish a constant supply of germs and poisons that finally cause serious diseases, such as rheumatism and heart trouble. One of the difficulties in curing these diseases is to find the source, or *focus*, of infection, that is, the place where the germs are producing their poisons.

When a doctor examines a patient, he looks for signs, or *symptoms*. We say that he makes a *diagnosis*. Headache, a fever, chill, breaking out of the skin, pus, and many other symptoms give the doctor a clue as to what the disease may be. Doctors have watched the development of many cases of disease; therefore they can usually tell by the early signs what disease is making the patient ill. Scarlet fever nearly always begins with the same effects. The person thinks he is developing a slight cold. His nose runs, his eyes burn, his throat is sore, he has a "strawberry-red" tongue, and a slight fever develops. Soon the fever increases, and a bright red *rash* appears upon the skin. Other diseases have their own peculiar early signs.

FIG. 158. The doctor is looking for symptoms of disease. (Ewing Galloway)

*Self-Testing Exercises.* 1. How are germs like other living plants and animals in the things they need to keep them alive and to make them grow? How are they unlike other living things in these ways?

2. How many bacteria could be produced from one bacterium in an hour? Why cannot bacteria reproduce at this rate for a long time?

3. What is a toxin? What effect does it have?

4. How may an infectious disease cause an organic disease?

5. How do doctors diagnose a disease?

*Problems to Solve.* 1. Describe how you felt when you were coming down with some disease that you may have had, such as

FIG. 159. Doctors and nurses are careful to bandage wounds in order to keep germs from getting into the wounds and into the delicate organs inside our bodies. (Ewing Galloway photo)

measles or scarlet fever. What did the doctor do to discover what kind of disease you had?

2. Consult reference books to find what the symptoms of various kinds of diseases are, or ask your doctor what the symptoms are.

## 3. How do our bodies fight disease?

HOW DO OUR BODIES KEEP OUT GERMS? Think of the countless number of germs we come into contact with almost all of the time! Why is it that most of us are able to go healthily and happily along, scarcely ever thinking of diseases at all? One reason is that our bodies are so constructed as to make it hard for germs to get inside. First of all, the entire body is covered with a protective layer of skin that keeps germs from getting to the more delicate inside parts. Most infectious diseases enter our bodies through its openings, such as the mouth and nose.

But even here the body has ways of protecting itself. The cilia (tiny, live hairs) that line the air passages to the lungs sweep dust and germs back toward the outside (page 215). The sticky liquids given out by the cells catch germs, stick them together, and help us get rid of them. Coughing and sneezing help blow dust and liquids containing germs out of our air passages. Many germs that get into the stomach are killed by the juices in the stomach. Thus, you see, germs may have quite a hard time getting into our bodies.

HOW DO WHITE CORPUSCLES FIGHT GERMS? Suppose germs do get into your body through the protective covering of the skin or through the mouth or nose. What happens in your body then? Whether the germs locate themselves in a break of the skin, in the throat, in the lungs, or in any other part of the body, you still have something to help you fight them. As you learned in Unit 7, the blood contains many tiny, colorless cells known as white corpuscles. When germs get into the body and begin to grow, the white corpuscles travel to the place where the germs are. These corpuscles then take in the germs, kill them, and change them into substances harmless to the body.

If the body is in good condition, there will be plenty of white corpuscles free to attack germs. In this way the white corpuscles often keep us from having diseases. Up to a certain amount, the healthy body can also manufacture more white corpuscles as they are needed. This usually happens when there is some infection in the body. One of the tests used by physicians is the *blood count*. In this test the physician counts the number of red and white corpuscles in a certain amount of blood. If the number of white corpuscles is too high, the physician knows that there is infection somewhere in the body, because the body is manufacturing extra white corpuscles to fight the infection.

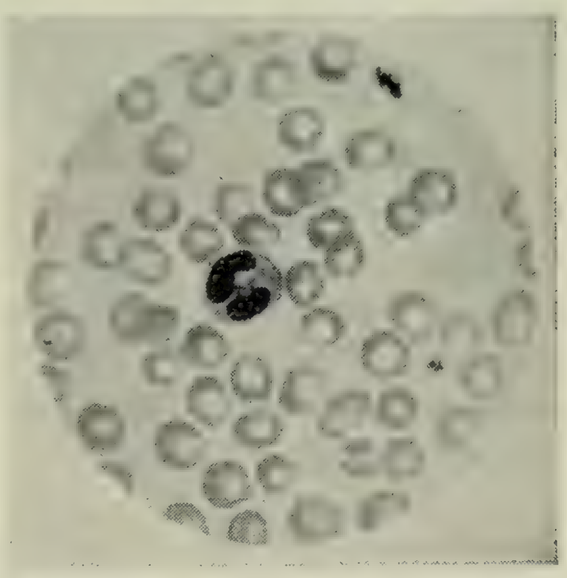


FIG. 160. Red-blood cells and one white corpuscle, which is plainly visible near the centre because it has been colored by a dye. (Bausch & Lomb photo)

Doctors tell us a very startling fact that shows how the white corpuscles protect us. They say that there are very few adult people whose lungs do not have some *scar tissue* in them. This scar tissue is caused by tuberculosis germs that began their work and were stopped by the white corpuscles. Indeed, it seems that our bodies are battle-grounds of a constant warfare between disease germs and the white corpuscles.

WHAT GERM-FIGHTING CHEMICALS DOES THE BODY MAKE? In addition to its protection from germs by means of a skin covering, tiny hairs in the breathing tubes, and white corpuscles, your body has another way of fighting disease germs. Your body manufactures chemicals that help to keep you from having diseases. Some of the chemicals make it easier for the white corpuscles to attack the bacteria. Others cause bacteria to stick together in bunches, so that they cannot spread over the body. Some chemicals actually kill and dissolve bacteria. Other chemicals change the toxins produced by germs into harmless substances. These last kinds of chemicals are called *antitoxins* (*anti* means "against," and, as you know, *toxin* means "poison").

Most people who have not had scarlet fever take this disease when they get some of the germs in their bodies; yet it is seldom that a person has the disease a second time. Why is this true? Scientists have found that if you have scarlet fever, the chemicals produced to fight the scarlet-fever germs and toxin remain in your body during the rest of your life. Then you are said to be *immune* to that disease. Diphtheria, mumps, and measles are other diseases that usually leave your body immune after one attack.

Suppose that you develop fever. The fever is a sign that you have some kind of disease germ in your body and that your body is fighting to overcome the germs. You should recognize fever as a sign that your body is fighting disease germs, and you should help it by going to bed and keeping quiet. If you exercise and eat foods that are hard to digest, then your energy will be used up in building new cells and in digesting food; therefore your body may not be able to make germ-fighting chemicals rapidly enough to win the battle against disease.

*Self-Testing Exercises.* 1. In what three ways does the body protect itself against the entrance of germs?

2. How may the stomach help protect the body against germs?

3. How do the white corpuscles help the body?

4. Suppose you are not feeling well. Your doctor makes a blood count and tells you that you have more than the usual number of white corpuscles. What would this tell you?

5. Explain why it is usually impossible for a person to have such a disease as scarlet fever more than once.

FIG. 161. Samples of streptomycin, the germ-killing drug produced by mold-like bacteria, are carefully tested. (Abbott Laboratories photo)

6. List some of the diseases to which people are immune after they have had them once. List some of the diseases that a person can have any number of times.

7. Have you ever been exposed to a disease, such as a cold, but did not take it? What reasons can you give to explain why you did not become ill?

*Problems to Solve.* 1. Find out exactly how a doctor makes a count of the white or red corpuscles in the blood.

2. What is the normal count of white-blood corpuscles for a healthy person?

3. Sometimes the blood count is low. What does this show? What can be done to bring it up to normal?

4. Why is any kind of cut or break in the skin dangerous?

## ¶ 4. How can we help our bodies fight disease?

HOW CAN WE MAKE OUR BODIES PRODUCE GERM-FIGHTING CHEMICALS? Have you ever been vaccinated for smallpox? Was your arm sore afterwards, and were you sick from the *vaccination?* How did this treatment help keep you from having the disease? About 150 years ago smallpox was a most dreaded disease. There was no known cure for it, and it has been estimated that in Europe during the eighteenth century one person out of every fifty died of smallpox.

An English doctor, Edward Jenner, noticed that many farm girls who milked cows became ill with *cowpox*, a disease of cattle similar to smallpox. Some of the substance from cowpox sores got into the bodies of the girls through scratches upon their hands. The cowpox sores soon healed, and the girls seemed to be immune to smallpox. Jenner used this idea in protecting people against smallpox. He made a small scratch on the skin and placed some of the substance from cowpox sores upon the scratches. This was the beginning of vaccination.

When you are vaccinated against any disease, a substance called *vaccine* is put into your body in some way. This vaccine may be made of weakened or dead germs, weakened toxin, or toxin mixed with antitoxin, depending on the kind of disease. The cells of your body then begin to manufacture chemicals, or *antibodies*, to fight the vaccine. These antibodies stay in your body and make you immune to the disease. The antibodies caused by smallpox vaccination remain in the body for about seven years. When the body becomes immune by working against poisons and producing its own antibodies, as with smallpox, we say the body is protected by *active immunity*.

That this method of preventing disease and death really works is shown wherever records are kept. One city had 3811 cases of smallpox over a certain period of years. One hundred seventy-one of these persons died, but among these there was not a single person who had been properly vaccinated. Army records show that of approximately 100,000 soldiers who took part in the Spanish-American War about 10,000 had serious cases of typhoid, and 1500 died. In World War I all soldiers were vaccinated against typhoid and paratyphoid. Out of 4,000,000 soldiers there were only about 300 cases of typhoid and 23 deaths. Surely these figures prove beyond doubt the value of vaccination.

HOW ARE DISEASE-FIGHTING CHEMICALS MADE OUTSIDE OUR BODIES? With some diseases, however, our bodies cannot produce their own disease-fighting chemicals fast enough. In these cases disease-fighting chemicals must be made outside our bodies and put into them. For example, if you should become sick with diphtheria, the doctor would put into your blood a liquid that contains antitoxin. Diphtheria antitoxin is secured

from horses whose blood has made protective substances. This method of protection gives our bodies *passive immunity*, so called because our bodies do not produce the antitoxins.

If you take *toxin-antitoxin* treatment against diphtheria while you are still free from the disease, your body produces chemicals to fight diphtheria germs and their toxins. Thus the treatment gives your body active immunity. There is a test by which you can tell, even before you are exposed to diphtheria, whether you would be likely to take it. This is the *Schick Test*, discovered only a few years ago by Dr. Bela Schick of New York City. A very small amount of diphtheria toxin is put under the skin of your arm. If a little red spot appears several hours later, you will be likely to take diphtheria if you are exposed to it. If no red spot appears, you are not likely to "catch" the disease.

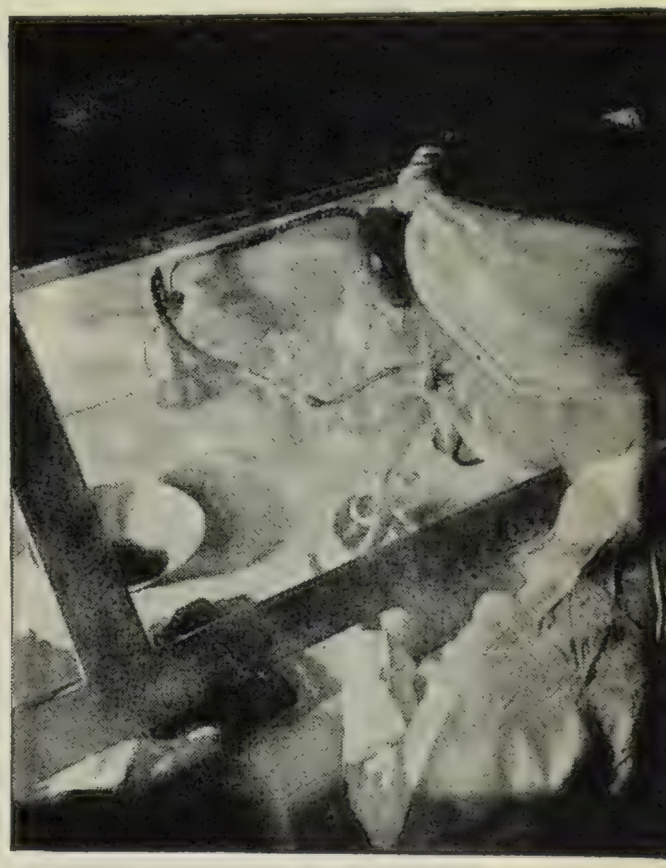


FIG. 162. Influenza vaccine is prepared by putting the virus into hens' eggs where it develops. Weakened virus is then made into a vaccine. (Sharp & Dohme photo)

When the Schick Test shows *positive* (a red spot appears), you are given toxin-antitoxin treatment; small amounts of diphtheria toxin-antitoxin are put into your blood. If you wait until after signs of diphtheria appear, you are given only antitoxin to help your body fight the disease. And if you wait until the disease has fully developed, antitoxin is much less likely to help you.

You can also take a test to show whether you would be likely to take scarlet fever. This test was discovered by Dr. George Dick and his wife, Dr. Gladys Dick, of Chicago and is called the *Dick Test*. Treatment consists of toxin and antitoxin that are prepared from a horse's blood. This treatment is very successful if it is given in time. The *tuberculin test*, which is given in a manner similar to the Schick and Dick tests, shows whether a person has been exposed to tuberculosis.

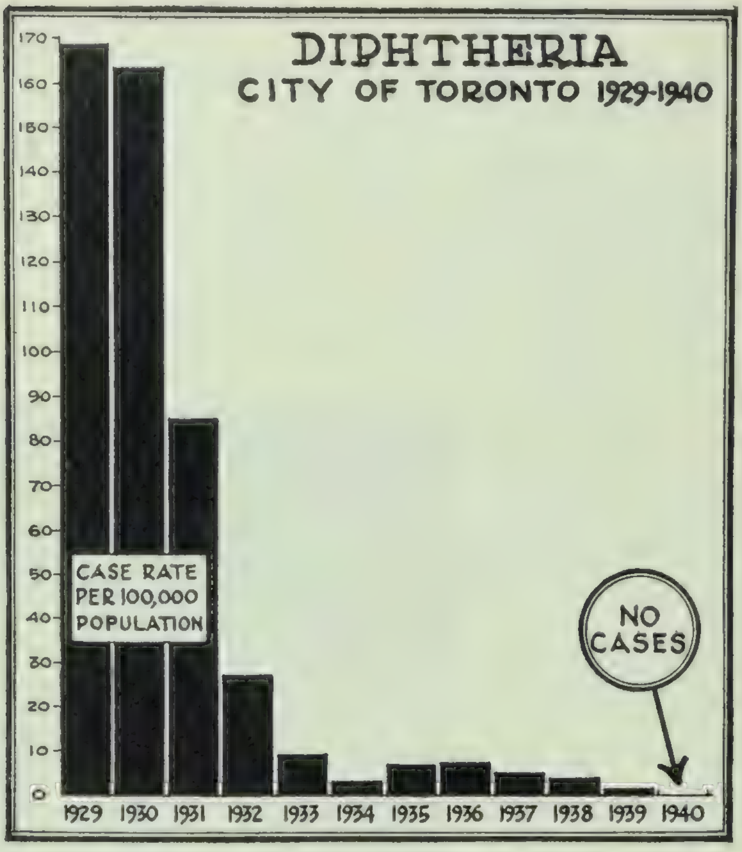



FIG. 163. This graph shows strikingly the decrease in diphtheria cases in a Canadian city since 1929, as a result of the toxin-antitoxin treatment. Notice what happened to the death rate when the use of antitoxin was begun. (Department of Public Health, Toronto)

We can also be made immune to lockjaw, typhoid fever, cholera, paratyphoid fever, Asiatic cholera, bubonic plague, yellow fever, some kinds of influenza, and rabies (caused by the bite of a "mad" dog). The method of immunization varies for each disease.

*Self-Testing Exercises.* 1. Explain what happened in the blood of the farm girls (described in the problem) when they had the cowpox that kept them from having smallpox.

2. What do we mean when we say that the body is immune to a disease?

3. What do the Dick and the Schick tests show?

4. What is the difference between active and passive immunity?

*Problems to Solve.* 1. Find out how diphtheria antitoxin is made from the blood of horses.

2. To what diseases are you immune? Tell how you became immune in each case.

3. Do vaccinations and inoculations last during a lifetime or for only a certain number of years? Find out how long they will keep a person immune.

## 5. How can we help prevent the spread of disease germs?

HOW ARE GERMS SPREAD? Have you ever had scarlet fever, diphtheria, or whooping-cough? Such diseases are called *contagious* diseases, because the germs that cause them are easily spread from one person to another. When contagious diseases spread rapidly and many people get sick, we have an epidemic. Sometimes epidemics kill a large per cent of the entire population. The terrible Black Death, which spread over both Europe and Asia about 600 years ago, destroyed about one quarter of the people of Europe. At least 25,000,000 persons died of the disease, which was really bubonic plague. More recently we have had epidemics on this continent, such as yellow fever in 1878, influenza in 1918, and infantile paralysis in 1934, 1935, and 1936.

As scientists have learned more about the causes of disease, they have been able to work out ways of checking the spread of infectious diseases from one person to another. Suppose you pass a friend's house on the way to school and see a *quarantine* sign on the door. What does this mean? It means that someone in the family has a germ disease, and that the family must stay away from others until the danger is over. Our bodies are natural living places for many kinds of germs, but some of these kinds cannot live outside the body for any length of time. So, in order to spread disease, these germs must be passed to well persons directly from sick persons. They may also be passed from persons who carry the germs in their bodies, but are not sick. Such persons are called *carriers*.

Perhaps you have wondered why you were kept out of school when you had been exposed to a disease, even though you were not sick at the time. Most diseases have a definite number of days from the time the germs enter the body and begin to grow until the person shows signs of the disease. This period is called the *incubation period*, and it varies with different diseases. For diphtheria the incubation period is from 1 to 5 days; for whooping-cough, 8 days; for chicken-pox, 11 to 22 days; for measles, 8 to 15 days; and for mumps, 15 to 22 days. When a person has been exposed to some kind of disease germ, he cannot be sure,


FIG. 164. What does this quarantine sign tell all the persons who pass or come to this house? (Ewing Galloway photo)

therefore, that he has not caught the disease until the entire period of incubation is over.

Even after a person has recovered from a disease, he still may be a carrier. For this reason the period of quarantine is usually continued for awhile even after a person has recovered. For some diseases, such as diphtheria, the health officer usually makes a *culture* from a person's throat before the quarantine is lifted. To do this he collects some of the mucus from the throat. Then he examines the culture made from this mucus to find out whether there are still disease germs in the person's body. If there are germs in the body, they will show in the throat culture.

Other examinations are made to be sure that the person is not a typhoid carrier. A certain cook in New York City, called "Typhoid Mary," was not sick herself, but she caused over twenty cases of typhoid fever before it was discovered that she was the source of the germs. Then, having agreed never to be a cook again, she did not keep her promise, and a few years later she caused many more cases of typhoid fever in a hospital where she went to work as a cook.

Let us see how germs are passed from one person to another; then you will know better how to protect yourself and others. When a person is ill, body discharges such as saliva, droplets from the nose and throat when sneezing, and discharges from intestines and from sores all contain germs. The *sputum*, coughed up from the lungs of tuberculosis patients, is especially dangerous. Disease germs may be spread in foods, such as milk,

meat, fruit, and vegetables. Dirty milk bottles and cans and dirty dairies where unclean people do the milking may start typhoid, diphtheria, tuberculosis, and scarlet fever. Tuberculosis is very common among cattle, and milk from a tubercular cow would be almost certain to spread the disease. What has been said about food applies equally well to water, except that germs find it harder to live in water than in food. There is, however, always the danger of typhoid and cholera germs in water in regions where these diseases exist.

FIG. 165. What an excellent germ carrier the fly's foot makes!

Any insect that touches germ-laden discharges from the bodies of people or of animals and then walks on food or on the bodies of healthy persons is liable to spread disease. The ordinary housefly is especially dangerous in this respect. Its feet, as shown in Figure 165, are very hairy. As the fly goes about to all kinds of filth, such as manure, garbage cans, toilets, and impure food, it picks up some of this filth. Later it walks on fruits and other uncovered foods or finds its way into our houses and to the table. As it walks, it leaves bits of filth containing disease germs.

FIG. 166. These colonies of disease germs grew on a gelatin culture after a fly had been allowed to walk over the gelatin.

Figure 166 shows what may be seen a few days after a fly is allowed to walk across some gelatin. Typhoid fever is so commonly spread by the fly that the name "typhoid fly" has been suggested for it. At one time scientists examined the feet of more than 100 flies to learn just how dangerous flies are. They found that each fly carried over one million germs. Next to the housefly, the cockroach is probably the most dangerous germ-spreader.

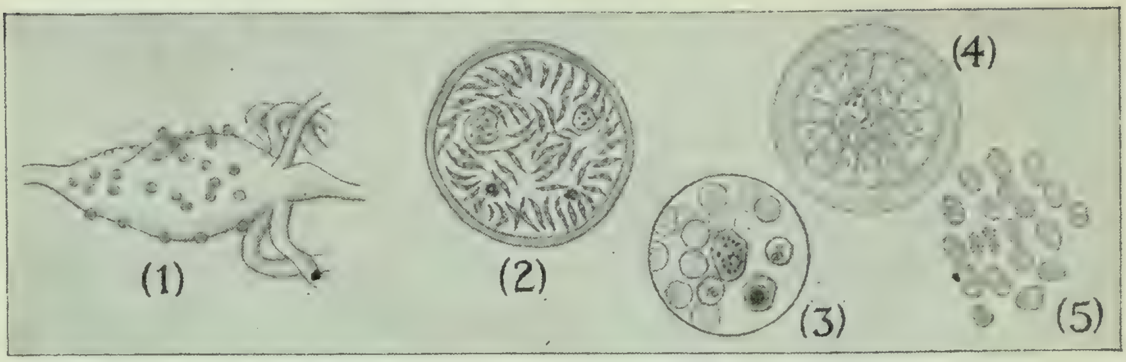



FIG. 167. The development of the one-celled animal germs that cause malarial fever is shown in these pictures. (1) The germs begin in small growths on the outside of the stomach of a mosquito that has bitten some person ill with the fever. (2) In each of these growths are many germs. (3) In picture number 3 one of the germs has entered a red-blood corpuscle of a person bitten by the mosquito. (4) In the corpuscle the germ divides into many parts, breaking the wall of the corpuscle. (5) The germs and their poisons enter the blood stream.

The second way in which insects spread disease is by their bites. Mosquitoes, ticks, fleas, and other insects may bite a sick person or other germ-carrier and thus take some of the germs into their own bodies with the blood, which is their food. In some cases the germs go through special stages of development in the body of the insect, as shown in Figure 167. Later, when the insect bites other people, some of the germs are injected into the blood of the new victims. Certain kinds of mosquitoes are the most dangerous germ-carriers of this type, although the mosquito most common in our country is practically harmless. Perhaps best known for their danger are the mosquitoes that carry malaria and yellow fever, a particular kind of mosquito for each disease (Figure 168). In some tropical regions, such as India, millions of people have died of malaria in a single year. When one speaks of the "deadly climates" of the tropical regions of the British Empire, he generally refers to malaria.

Yellow fever is another mosquito-borne plague. The disease struck first in the West Indies in 1647, spread through Central and South America, and was carried to Europe. At Georgetown, British Guiana, 69% of the garrison were carried off in 1840, and thirteen years later 8000 people died in New Orleans. But the beginning of the century saw the disease under control, and the completion of the Panama Canal is almost as great a

tribute to the doctors who stamped out yellow fever as to the engineers who constructed the works.

Several other insects which spread germs through their bites are worth knowing about, although they are less important than the mosquitoes. In the fourteenth century approximately twenty-five million people died in Europe of the terrible bubonic plague, which was carried by rats and fleas. Rats have the plague, and

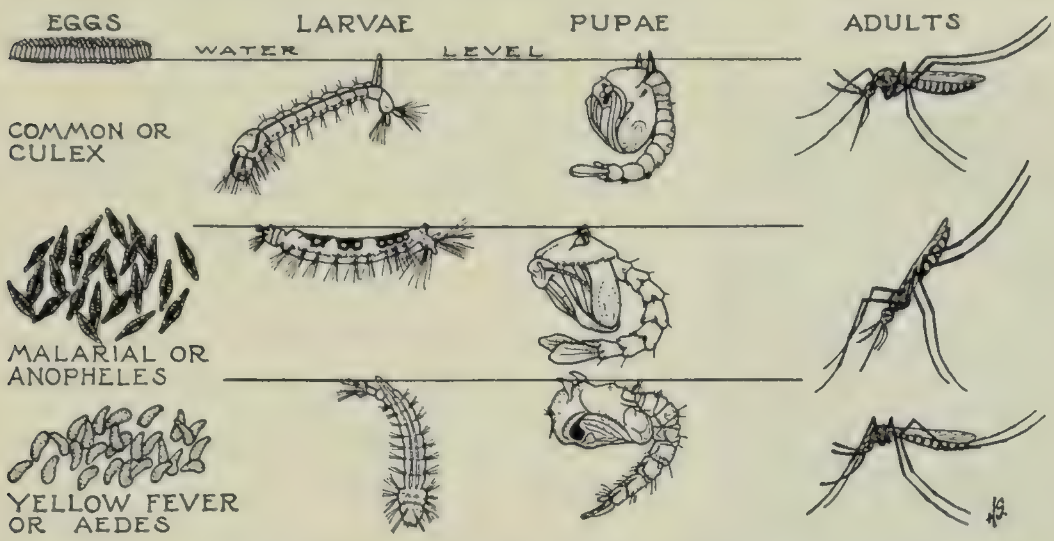



FIG. 168. Each of these three kinds of mosquitoes develops through four stages: egg, larva, pupa, and adult. In the larva and the pupa stages they get air through tiny breathing tubes which extend slightly above the surface of the water.

fleas transmit the plague germ from the rats to human beings whom they bite. At that time it was not known how the disease was carried. Typhus fever, spread by body lice, has caused and still causes many serious epidemics in certain parts of the world. Relapsing fever is spread by bedbugs, lice, and ticks. The sleeping-sickness of Africa is spread by the tsetse fly.

The story of disease-carriers of this type should, no matter how short, contain a word of praise, a tribute, for those noble men who have offered their lives that we may know the cause of disease and the methods of spreading germs. One case will illustrate the spirit with which true scientists work. In 1900 four doctors were sent to Cuba to study the cause of yellow fever. The disease had killed thousands of people every year throughout the Indies. These scientists thought the disease might be due to certain mosquitoes.

There was only one way by which the doctors could prove their idea and that was to allow themselves to be bitten by the mosquitoes. Two of the brave doctors took the disease. One recovered after a severe illness, but the other, Dr. Jesse W. Lazear, sacrificed his life for the sake of his fellow-men. The doctors called for volunteers to help them, and two young men offered themselves. Both came down with the disease and later recovered, but one of them became physically disabled by the experiment. Because of what was learned, the disease was under control within two years.

FIG. 169. On a memorial tablet to Dr. Jesse W. Lazear are these words: "With more than the courage and devotion of a soldier, he risked and lost his life to show how a fearful pestilence is communicated and how its ravages may be prevented."

In addition to the germs that live inside our bodies and are passed from person to person, there are germs that ordinarily live outside the body. When these germs get into the body through cuts, sores, or other breaks in the skin, sickness and death often follow. The lockjaw germ, for instance, seems regularly to live in the intestines of horses and other animals without doing any harm. Thus, wounds received in the neighborhood of stables or in fields fertilized with manure are especially liable to cause lockjaw (tetanus). A very high percentage of the wounds in the early days of the World War of 1914-1918 produced lockjaw because the fields in which many of the battles were fought had for years been fertilized with manure.

*Self-Testing Exercises.* 1. What is meant by the incubation period of a disease?

2. In what ways may germs be spread from sick people to people who are well?

3. What are the two ways by which insects spread disease? Explain each way fully.

4. Is this statement true? A person sick with a contagious disease is a carrier of that disease, but a carrier of a contagious disease does not have to be a sick person. Explain.

HOW CAN YOU HELP KEEP GERMS FROM SPREADING? So easy is the transfer of germs from sick persons that unless we know how to kill germs, it is hard to keep them from reaching well persons. Germs thrive best and usually live longest in moist, dark, warm places where there is food for them and where the chemical conditions are suitable. By placing the germs under other conditions, their growth is stopped, or they are killed. Thus many kinds are killed by being dried out. Most kinds of germs cannot live if they are heated to the temperature of boiling water, especially if they are in actual contact with the hot water. Very high temperatures destroy all germs. Sunlight is very injurious to them, and many articles that cannot be freed from germs in any other way may be exposed to sunlight and air for a few hours.

There are many chemicals, too, that are noted for their ability to prevent the growth of, or to kill, germs. Such chemicals are known as *antiseptics*, *disinfectants*, or *germicides*. The word "antiseptic" means a substance that prevents the growth and development of germs but does not necessarily kill them. Disinfectants or germicides are good germ-killers. Some common disinfectants are poisonous if they are taken into the body in any considerable quantity. Such poisonous disinfectants are formaldehyde gas (known as *formalin* when dissolved in water), corrosive sublimate (bichloride of mercury), iodine, carbolic acid, and silver nitrate. But there are other good germ-killers that are not violent poisons. Some of these are peroxide of hydrogen, potassium permanganate, mercurochrome, and alcohol. Chlorine gas is poisonous if breathed in large amounts; but if it is dissolved in water in very small amounts, it does not seem to be harmful to the body and yet is quite effective in killing germs.

Most of the disinfectants are dissolved in water or alcohol, but a few are used in the form of gases, as, for example, when whole rooms must be disinfected, or *fumigated*. When the disinfectant is in the form of a gas, it can get into every crack and corner of the room and into all the clothing and furnishings. In using any poisonous disinfectant, with the possible exception of iodine solution, you should consult a good druggist or a physician. The process of killing all the germs that may be on objects or in substances is known as *sterilization*. Objects or materials free

from germs are said to be *sterile.* The sterilizing, or disinfecting, agents that you should always keep in mind are heat, water or alcohol containing germicides, and sunshine.

Certainly the best way to avoid "catching" a disease is to keep away from people who are ill. But many times this is not possible. How can you protect yourself then? Everyone must be careful not to touch persons or animals with contagious diseases and, when sick, must not touch well persons. But we are not willing to be careful enough, and we cannot always know who is carrying germs about with him. A person ill with a contagious disease may carry on his usual activities for a day or two before finding out why he is feeling so miserable. It is well to wash your hands thoroughly with soap and water at the first opportunity if you have shaken hands with large numbers of people. If you only stop to think, you will realize that no sensible person would put another's pencil in his mouth, eat of the same candy or other food, bathe in a dirty bathtub, use an unclean toilet seat, sleep on bedclothes that were used by a sick person and not disinfected, or use a dirty handkerchief or roller towel. At all times it is safer to avoid using the personal belongings of others.

FIG. 170. Sterilizing surgical instruments in a large hospital in New York City (Ewing Galloway photo)

Quarantine helps prevent the spread of germs by direct contact as well as by other means. If you are quarantined, you should be very faithful to obey the law, regardless of whether or not the disease seems dangerous to you and no matter how uncomfortable such quarantine may be.

Proper regard for your own well-being and for those about you is one of the easiest and most successful ways to keep germs from spreading. Even before you come down with an infectious disease, you can know that you are becoming sick. Coughing or sneezing, sore throat, fever, headache, vomiting, diarrhoea, rash

breaking out on the skin, feeling tired and lazy, and having chills are some of the symptoms that you may be taking or have taken a disease. In such cases it is your duty to stay in your room and to call a doctor. To go out and be with other boys and girls is most unfair to them, and, besides, to do so may endanger your own health.

Every kind of food that is to be used without thorough heating must be carefully guarded against contamination by discharges from sick persons and "carriers." In the larger cities all men who handle milk are carefully examined. There should be laws, as there are in some cities, which require that cooks and waiters in public eating places be regularly examined. All milk should come from healthy cows, kept in clean stables and milked by sanitary methods. Tubercular cows should be discovered by testing, at regular periods, all cattle in herds whose milk is used for human consumption. All infected cattle should then be killed, for there is no cure for them.

To kill any germs present in milk, the milk is *pasteurized* by heating it to a temperature of 144° F. for about thirty minutes. Pasteurization does not kill all of the bacteria in milk; it does, however, kill most of them, and especially the ones that cause disease. The majority of cities have laws prohibiting the sale of milk that has not been pasteurized. In rural communities milk is often not pasteurized.

In the home equal care must be practised. Thousands of babies die because their milk bottles and the rubber nipples are not kept clean. Being a baby is the most dangerous life in the world, simply because older people are careless. And milk is one of the greatest sources of danger to the baby. If bottles are not kept in the refrigerator, caps are removed and not replaced, glasses are not cleaned properly, hands are not washed before handling the bottles, and the mouths of bottles are not kept clean, it is easy for germs to get into the baby's milk.

Practically every large city in the world finds it necessary to spend much money to keep its water supply from becoming polluted and to purify it. Similarly, in the country, every precaution against water-borne diseases should be practiced. In Unit 11 you will learn how this is done.

Next to food and water, flies are probably the most dangerous spreaders of germs. In manure piles, garbage cans, open toilets, rubbish piles, and sewage the fly finds its appetizing food and a most desirable place to raise its young. Here the female fly may lay from 120 to 150 eggs at a single time. Four or five such batches may be laid during a season. Thus, within a season a single fly may produce over five hundred new flies, each of which endangers our lives. And as each female fly becomes two weeks old, she may lay eggs and so produce still more. Thus a single fly may start to multiply in April and bring into the world 6,000,000,000,000 flies by September.

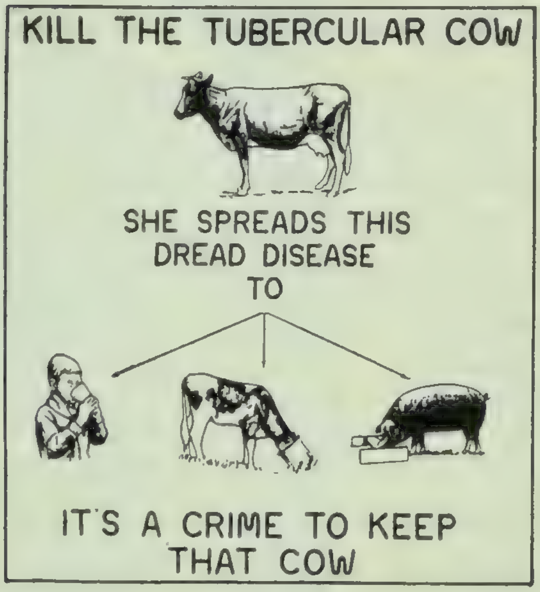



FIG. 171. This poster has been used in a nation-wide war on the tubercular cow.

The best way to fight the fly is to keep the fly from multiplying. Every one of the above-mentioned homes of the fly can be treated with chemicals that kill the fly eggs and that keep the fly from spending its time in such places. For these purposes borax may be spread on manure, and lime or bleaching powder may be placed in garbage, open toilets, rubbish piles, and sewage. Garbage cans can be kept clean and covered, and the garbage can be regularly disposed of. Open toilets may be done away with by building septic tanks, about which you will learn in Unit 11, or they may be protected by screens. Rubbish piles can be burned or hauled away.

The principal methods by which the danger from all kinds of mosquitoes can be controlled are (*a*) preventing their growth, (*b*) killing the *larvae* and the *pupae*, and (*c*) protecting ourselves against the full-grown mosquito. We can keep mosquitoes from growing by doing away with their breeding places. Common methods of doing this are protecting cisterns, cesspools, rain barrels, sinks, and water pails with screen or covers, by draining and clearing swampy regions, by burying tin cans and other un-

Fig. 172. Aeroplanes are used to spray DDT, the powerful insect killer, on large areas where mosquitoes breed. (Acme Telephoto)

necessary receptacles in which water may stand, by keeping the channels of streams clear of grass and weeds, and by draining standing pools along the banks.

Killing the larvae and the pupae may be done by spreading oil on the water every few weeks in the spring or by stocking any ponds with fish and frogs. The oil floats in a thin layer over the water. The larvae and pupae, which must breathe, cannot get air because the oil fills their breathing tubes, as you can easily see by referring to Figure 168. Moreover, the adult mosquitoes cannot rest on the oily surface of the water, and therefore cannot lay their eggs. The fish and frogs that are in the streams or ponds feed on the larvae, or wrigglers.

Painstaking care and thoroughness are also required to control bedbugs, lice, and fleas. Of course, no respectable person tolerates vermin today, but vermin control becomes difficult when great numbers of people are thrown together under unusual conditions. During a war the clothing of the soldiers is regularly put through a "delousing" process to eliminate insects, largely because they are dangerous as disease-carriers. In certain parts of our country, where the bubonic plague sometimes occurs, great care is observed to prevent the immigration and increase of rats and ground squirrels which, with the fleas they carry, transmit the plague.

*Self-Testing Exercises.* 1. What disinfectants and antiseptics do you use in your home? Do you know that they are effective? How?

2. State three things which you can do to prevent spreading germs by coughing, sneezing, or spitting.

3. Make a list of the ways in which disease germs may be passed from one person to another. For each item in your list tell how this transfer of germs can be avoided.

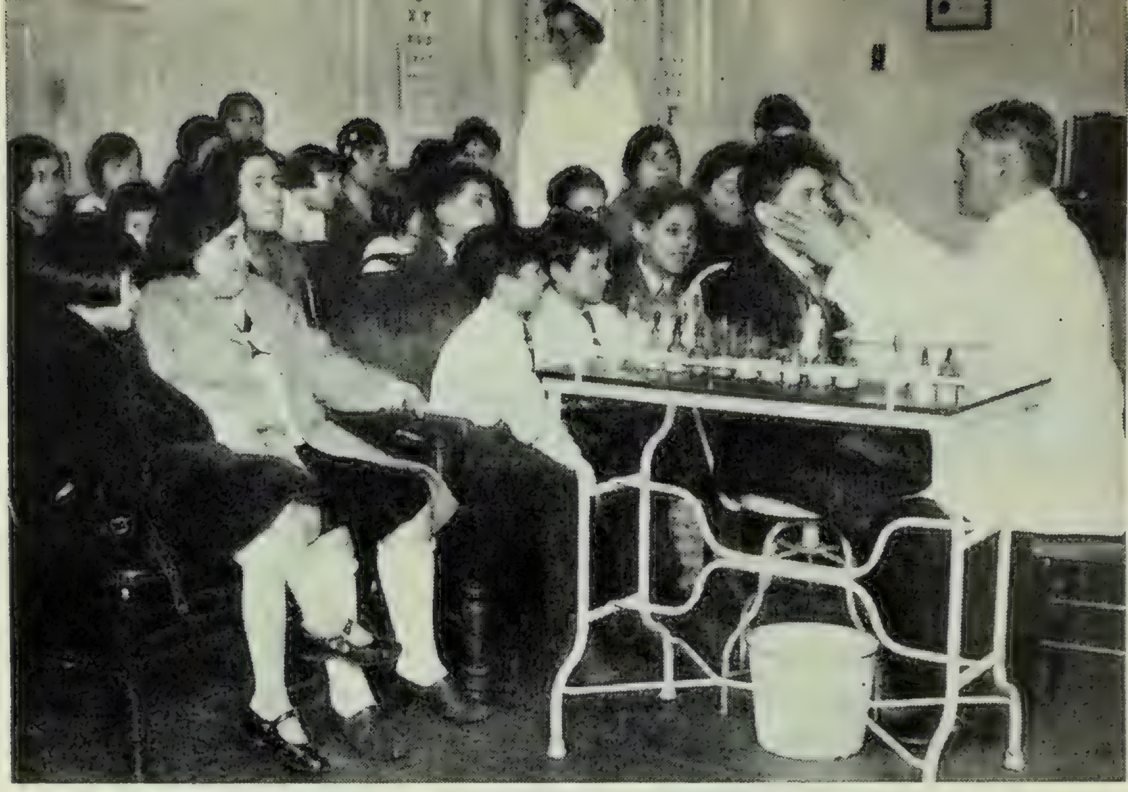


Fig. 173. Doctors make many tests to find whether people are in good physical condition. In this health clinic the doctor is examining the eyes of all the children in a school class. (Ewing Galloway photo)

4. List as many ways as you can to keep germs from getting from sick people to well people.

5. Tell how to keep germs from getting into your body through a broken place in the skin.

*Problems to Solve.* 1. With the aid of your class, make a list of all the diseases that your classmates have had during the year. For which of these should people be quarantined?

2. Make a list of ways in which disease epidemics could be started in your community. Opposite each item in this list tell what your community does to prevent epidemics.

3. In reference books read about plagues that have swept over parts of the world at various times in history.

WHAT IS PREVENTIVE MEDICINE? Does it seem strange that in some countries people used to pay doctors to keep them well? People did not wait until they were sick to send for a doctor. They paid doctors to tell them how to keep from having diseases. People are coming to realize that this was a good practice; so today we are learning to keep diseases from getting started, instead of waiting until we are sick and then running the risk of not being able to be cured. Such practice is called *preventive medicine.*

How does preventive medicine work? Have you ever heard someone say that his body was in a "run-down" condition and

that he needed to "build himself up" for fear he would take some disease? He meant that his body had become weakened in some way, and that he did not have the extra energy needed to fight germs if they got into his body. It is best for you to keep in good physical condition at all times, for you never know when you may be exposed to germs. Such diseases as pneumonia, tuberculosis, and common colds seem to attack our bodies much more easily when we are in a "run-down" condition. You can help your body fight these diseases by keeping yourself in good condition all of the time, instead of waiting until you are sick to take care of yourself.

You can go to a reliable doctor at least once a year to find out whether your body is working properly. If you find that you have bad teeth, bad tonsils, or other defects, you can have these treated before they injure some vital organ of your body, such as the heart or lungs. You can get plenty of sleep, eat the right kind of foods, play in the fresh air and sunshine as much as possible, and keep your body clean. When you do these things, you are at least giving your body a chance to do its work well. Of course, if you become ill with a disease, you should call a good doctor as soon as possible and do as he says. A good doctor follows the best practices of the medical profession and does not advertise quick cures or depend upon patent medicines. He suits the treatment of each disease to the needs of the person he is treating.

What are some other good health habits that you can have? You can think straight about your health problems instead of worrying about yourself. You can be willing to change your opinions about health matters as new discoveries are made. You can select wisely the doctors to whom you go so that you can have confidence in them. Having confidence that you will win when you and the doctors are following the best practices will help you and your community in the fight against disease.

What has just been said about preventive medicine helps each of us as individuals, but that is not enough. We must be willing to work with others in securing healthful conditions for our community. If our neighbor is careful in his health habits, while we are careless and expose him to diseases that we have taken, we undo all the good that he has done.

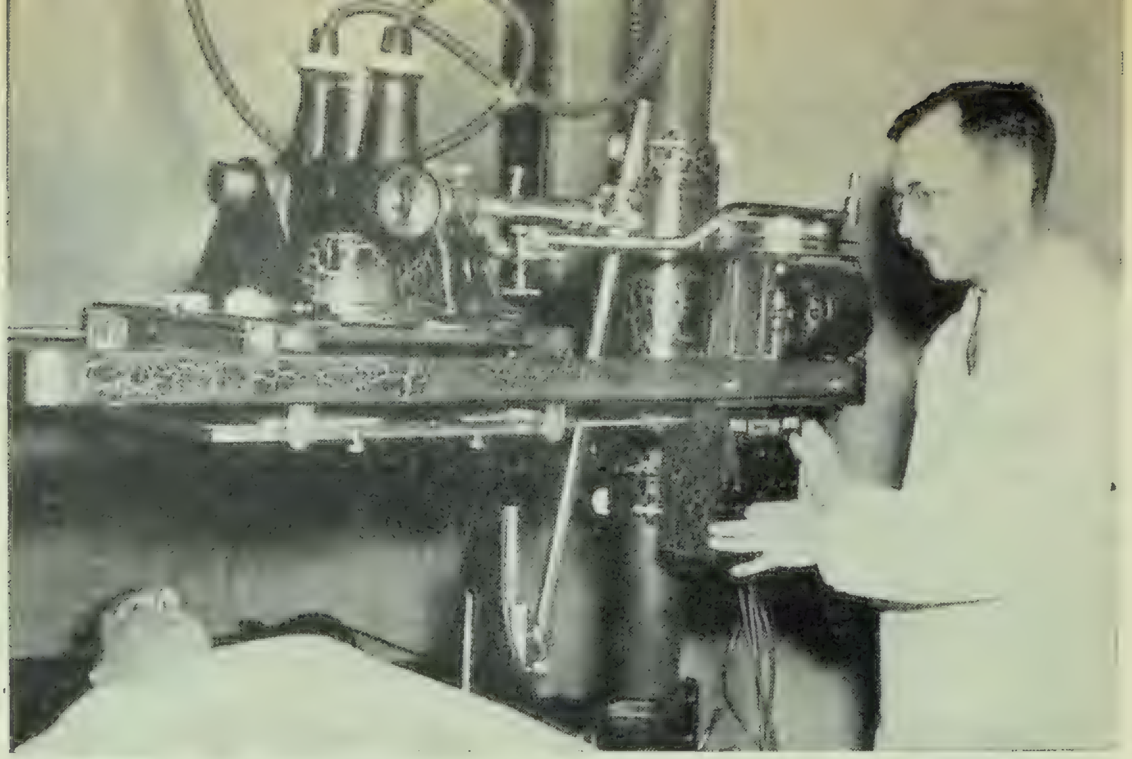


FIG. 174. One of the greatest aids to preventive medicine is the X-ray machine. The rays of this machine can go through the human body and make a photographic plate of the organs, the flesh, and the bones. This photograph enables the doctor to discover some diseases in their earliest stages, when they can be cured more easily. (Century photo)

We can learn to work together to rid our homes first and then our communities of insect pests, such as flies and mosquitoes. We must be willing to have ourselves vaccinated against infectious diseases, and we must be honest in obeying quarantine rules when we have an infectious disease. We can insist that our food and water supplies be protected from germs and from the insects that carry germs.

*Self-Testing Exercises.* 1. What practices of preventive medicine do you follow regularly?

2. List the practices of preventive medicine that you should, but do not, follow.

3. Make a list of ways in which people of your community work together to make it a healthful place in which to live. Suggest other ways that would help.

## Looking Back at Unit 8

1. Answer the following questions, using a paragraph of at least one-third of a page for each question. Work with your book closed.

*a*) What kinds of plants and animals cause disease?
*b*) How do germs make us sick?
*c*) How does your body protect itself against disease germs?
*d*) How can we help our bodies fight disease?
*e*) How can we help prevent the spread of disease germs?

2. Show that you know the meaning of each of these words.

| | | | |
|---|---|---|---|
| *antibody* | *carrier* | *active immunity* | *antiseptic* |
| *toxin* | *antitoxin* | *passive immunity* | *fumigate* |
| *vaccine* | *vaccination* | *incubation period* | *pasteurization* |
| *epidemic* | *symptom* | *infectious disease* | *sterilization* |
| *coccus* | *bacillus* | *organic disease* | *spirillum* |
| *organism* | *quarantine* | *contagious disease* | *germicide* |

## Additional Exercises

1. Find the difference between *certified* and *pasteurized* milk. Which is more expensive? Why?

2. Learn how milk is pasteurized. Pasteurize a sample of milk and compare it with a sample of raw milk. Which spoils the quicker?

3. To find what a germicide does, ask your teacher to put three drops of mercuric-chloride solution into a test-tube of milk. Label the test-tube "poison." Smell the milk in the tube after several days. Has it curdled or soured? Keep a second test-tube of milk with the first one, but put no mercuric chloride into it. How does it act? Explain the difference. (NOTE: *Do not attempt this exercise except under the careful direction of your teacher.*)

4. Does weather have any effect upon disease? Keep a record of the number of days missed from school by the members of your class on account of sickness. Make this into a graph. During what months were there the most absences? What kind of weather generally prevails in your locality during these months?

5. Examine a fly's foot under the low-powered lens of a microscope. Does this help explain why the fly is a carrier of disease germs?

6. Find how the following men helped in the fight against disease germs: Edward Jenner, Robert Koch, Joseph Lister, Louis Pasteur, Walter Reed, Paul Ehrlich, and William Osler.

7. In reference books find graphs for other diseases, like the one for diphtheria on page 256. Or get the figures from health reports for your city or province and make graphs for your class. What do they show?

8. Dip up a glass of water from a still pool of water in some swampy place. Examine it to see whether there are any mosquito larvae. If there are, keep the glass covered with a cloth and watch the larvae develop into wrigglers and adult mosquitoes.

9. Find out what regulations your town or city has regarding protection of milk supply, food supply, water supply, etc.

10. Explain why nurses and surgeons wear white gowns and cover their mouths and noses with gauze in the operating rooms.

11. If a large number of cases of typhoid fever suddenly developed in your town, what should the health authorities do? What should you do for your own protection?

## Books to Read

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ABOUT 1000 YEARS AGO, this was the best men could do to heat their homes. A hole in the roof carried away the smoke, and much of the heat escaped with the smoke. There was no way to carry the heat from a fire in one part of the building to rooms in other parts. Men had not yet learned how to control heat for their uses. In this unit you will learn many of the things that scientists have discovered about heat.

# UNIT 9

# How Do We Control Heat?

## Looking Ahead to Unit 9

George was trying to melt some lead in a metal spoon. He put the lead in the spoon and held it over a gas-burner. Soon the spoon became so hot that he had to drop it. His father saw what had happened and gave him a spoon with a wooden handle. "Here, George, use this spoon. Wood is a poor *conductor* of heat and will not let your hand get burned." What did George's father mean when he said that wood is a poor conductor of heat? How does heat move from one place to another? Why do we now have homes that are heated so much better than the homes of 200 years ago? How can electricity be used to remove heat from a refrigerator? Can you give the answers to all these questions?

Early people believed that heat was some kind of invisible liquid. They thought that this liquid moved from place to place in materials much as water is soaked up by a sponge. When materials were heated, they soaked up a large amount of this invisible liquid. When a material became cold, in some way the liquid left it. This seemed like a good theory. It explained how things became heated and cooled and why they expanded when they were heated and contracted when they were cooled. But some things about the way heat acts could not be explained by this theory; therefore scientists changed their ideas.

You have learned that heat is one of the kinds of energy. When materials are cold, they contain little heat energy; when they are hot, they contain much more heat energy. Heat makes materials expand, and it makes them change their state. Even though you have learned these things, you probably do not yet know just what heat energy is. What heat energy is will be one of the things to learn in this unit.

FIG. 175. In each picture heat is travelling in a different way. At the right the girl is warming her hands by holding them on warm metal. In the centre a current of warm air is moving up from below. In the picture at the left radiant energy is travelling to the girl's hands, where it is changed into heat. Problem 1 will explain these three different methods of heat transfer.

People's methods of heating their homes and other buildings have changed as much as their ideas about heat. Now most homes are so well heated that we scarcely know whether it is winter or summer unless we go outside. From your study of this unit you will be able to understand how we use heat in our homes. You will see how it is possible to transfer heat from a fire to the air in a room or to other rooms far from the fire. You will also discover what happens to heat when a material changes from one state to another. When you understand this, you will see why a burn from steam is more painful than a burn from boiling water, how ice keeps things cool, and how it is possible to make ice with the aid of electricity.

## ¶ 1. How does heat travel from one place to another?

HOW DOES HEAT TRAVEL BY CONDUCTION? Without thinking, you have probably already realized the general rule followed by heat when it moves. Heat is always moving from places of higher temperature to places of lower temperature, or from warm places to cooler places. When you pick up a cold spoon, the spoon gets warmer, and your fingers feel cooler, because heat

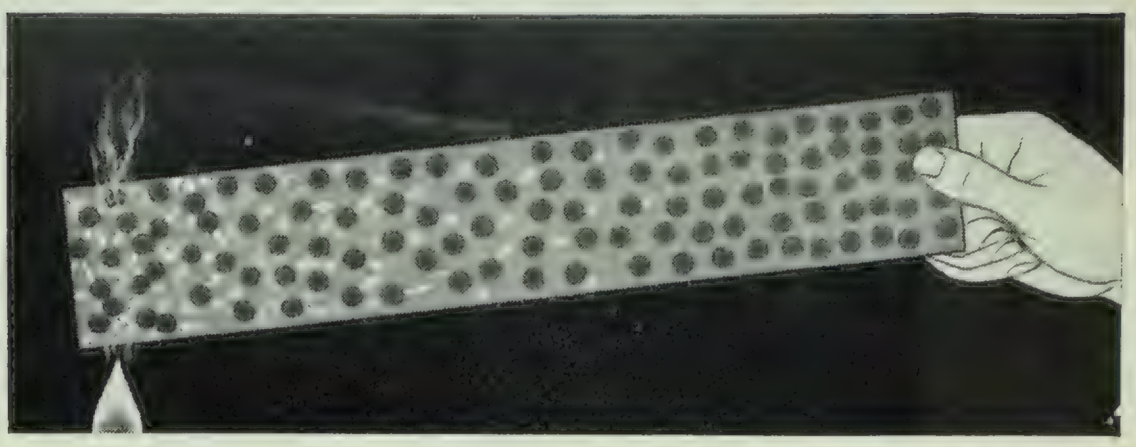

FIG. 176. This diagram will help you to understand how heat travels by *conduction*. After you have studied about conduction, a good test would be to explain exactly what this diagram shows.

is moving from your fingers into the spoon. When you pick up a hot spoon with your bare fingers, much heat moves from the metal into your fingers.

When heat moves away from materials that are hot, or have a high temperature, it may travel in three different ways. These ways are *conduction*, *convection*, and *radiation*. They are called the three methods of *heat transfer*. To find out how heat travels, you will first do an experiment to get some facts about the conduction of heat. Then you will see how these facts about the action of heat can be explained.

*Experiment 44.* HOW IS A PIECE OF METAL HEATED? With your fingers hold one end of a large nail in a flame for several minutes. What do you notice about the temperature of the nail? Does the nail become hot suddenly, or does it just get warmer and warmer? Rub your finger along the nail toward the flame. Where is the nail hottest? Coolest?

To explain how the heat travelled from the flame to the other end of the nail, you will need to know what is happening to the molecules in the metal. As you already know, the molecules of a substance are always moving. What happens to these molecules when a substance is heated? Scientists believe that when a substance is heated, its molecules move faster. When the molecules move faster, the temperature of the object rises. If metal feels cold, the molecules are moving slowly. If metal feels hot, the molecules are moving rapidly. Whether an object is hot or cold depends upon how rapidly its molecules are moving.

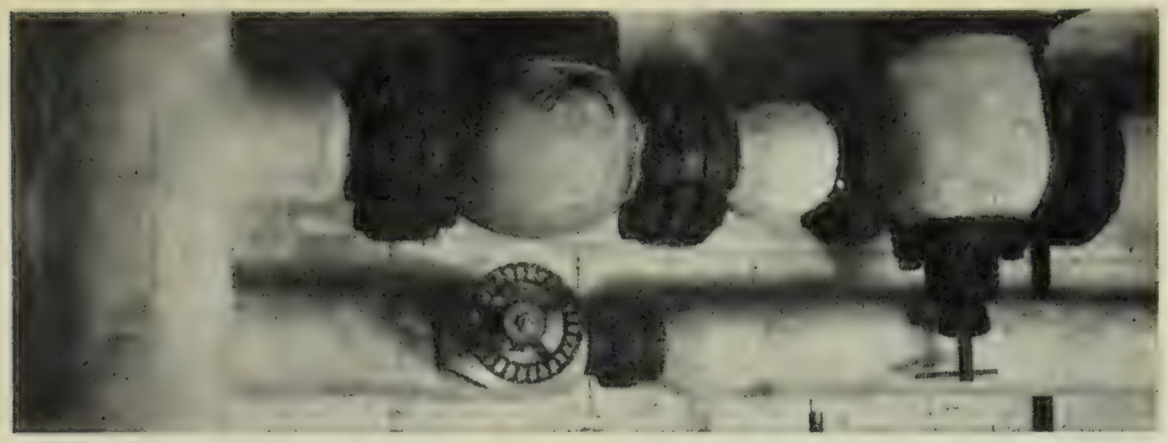

FIG. 177. These steam-pipes are covered with a layer of asbestos to prevent the escape of heat. Asbestos conducts heat very poorly.

Now to come back to the experiment. When the nail is held in the flame, the molecules in the part of the nail in the flame begin to bounce around faster. Since iron is a solid, the molecules cannot move very far before they bump into other molecules. When molecules get bumped, they start to move faster and bump the molecules next to them. In this way the molecules at the end of the nail in the flame start molecules moving faster all along the nail. When the molecules at the end in your hand begin to move faster, you feel the nail getting hotter.

This process of passing heat from one molecule to another is known as *conduction*. The word "conduct" means "to lead." It is a good word to describe this method of transferring heat, for heat seems to be led along as the rapidly moving molecules make their neighbors move. The transfer of heat by conduction is very important. When you build a fire in the stove, the heat from the burning fuel is conducted through the metal walls of the stove to the air that is touching the stove. We make our cooking pans of metal so that the heat from the fire may be conducted to the food. All metals are good conductors of heat. This is one reason why metals are used to make stoves, radiators, and cooking utensils.

For some purposes we want to stop the conduction of heat. You will be surprised to find how much we use poor conductors, or *non-conductors*, of heat. Handles of spoons used in cooking are often covered with wood, a poor conductor. When your mother places a hot dish on the table, she usually puts a napkin or other non-conducting material under it to keep it from ruining

the varnish. Materials that conduct heat very slowly are called heat *insulators.*

Gases, such as air, are very poor conductors of heat. You know that you can hold your hand close to a very hot iron without being burned. If air were a good conductor of heat, you would be burned. Almost any material with air spaces in it is a good insulator. Notice the asbestos pipe covering in Figure 178. The asbestos itself is a good insulator. But, in addition, the covering is made with air spaces in it. At the right is a pile of ground-up asbestos. This is made into paste by moistening with water and is then put on pipes to insulate them, as in Figure 177.

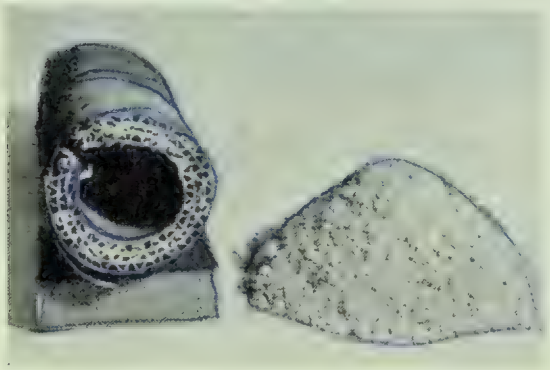

FIG. 178. Asbestos materials used for insulation

You wear woollen and fur clothes in winter because they are poor conductors of heat. In addition, wool and fur have many spaces filled with air, an even poorer conductor. When you pile blankets on top of yourself on a cold winter night, the blankets do not give you heat. They are poor conductors; they keep the heat of your body from escaping rapidly into the air of the room. Perhaps you have heard that a newspaper wrapped around you under a coat or placed between blankets will help you keep warm. Paper is a poor conductor of heat. In addition, the layers of paper hold air between them. The paper and the air together are good heat insulators.

*Self-Testing Exercises.* 1. Explain how heat is conducted through a metal rod by telling what happens to the molecules when one end is heated.

2. How do we use materials that are good conductors of heat? Materials that are poor conductors of heat? Give examples.

*Problems to Solve.* 1. Which of these are good conductors of heat: a bakelite cup, a porcelain knob, an aluminum pan, a brick, an iron shovel? If you do not know, how can you find out?

2. To keep warm in the winter, we usually cover ourselves with a woollen blanket. But we may also cover a piece of ice with a blanket

to keep it from melting in the summer. How does the blanket help us keep warm and help the ice keep cool?

3. If you were carrying ice-cream on a hot day, would it be better to use a tin bucket or a paper bucket? Why?

4. Birds ruffle up their feathers on cold days in order to keep warm. Explain how this helps.

5. The outer pail of an ice-cream freezer is usually made of wood, and the inner can is made of thin metal. The cream is put into the metal can, and the ice goes in the space between the wood and the metal. Explain why different materials are used in the two cans.

6. Wrap a piece of paper tightly around an iron rod. Hold the rod in the flame for a short time. Does the paper burn? Wrap the paper around a wooden rod and hold it in the flame for the same time. Explain the difference in what happens.

HOW DOES HEAT TRAVEL BY CONVECTION? Did you ever come into the house on a cold winter day and stand over the register of a hot-air heating system? If you have had this experience, you know that a current of air was bringing heat from the furnace to you. You have probably noticed that the air around a warm radiator or stove is always moving upward. But have you noticed that both air and water begin to move almost every time there is a slight difference of temperature between two places in these fluids? Let us watch the movements of air and water so that we can understand something important about how our homes are heated.

FIG. 179. Experiment 45

*Experiment 45.* HOW DOES WARM WATER BEHAVE IN COLD WATER? Obtain a wide-mouthed bottle that will hold about one-half pint. Have a stopper to fit. A wooden plug will do. Fit tubes in two holes in the stopper, as shown in Figure 179. Have these tubes as large as convenient. Put a few drops of ink in the bottle, fill it to the top with hot water, and put the stopper in tightly. Gently lower the

bottle into a jar or bucket filled with cold water. Be sure that the water in the large vessel reaches above the top of the tube that extends above the stopper. Where does the warm water go? What goes into the bottom of the bottle?

*Experiment 46.* HOW DO WARM AIR AND COLD AIR BEHAVE?. (*a*) Arrange an apparatus as shown in Figure 180. This is a box fitted with a glass front. Two holes are cut in the top of the box, and a lamp chimney is placed over each hole. A burning candle is placed inside the box directly under one of the holes. Hold a piece of smoking punk-stick or paper over the chimney that stands above the candle. Does the smoke move up or down?

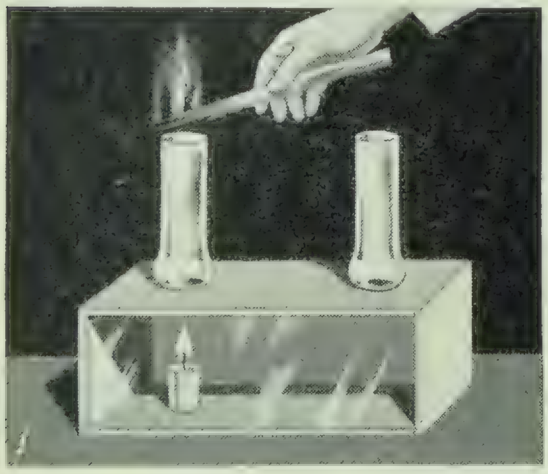

FIG. 180. Experiment 46

*b*) Now move the smoking paper or stick to the other chimney. What happens to the smoke? Make a drawing of the box, the candle, and the chimneys. Show the direction of the air currents by means of arrows.

If you will keep your eyes open, you will notice many examples of circulation like those in your experiments. Whenever you open an outside door in cold weather, the cold air pours in and flows along the floor, and warm air flows out the top. Most of the time there is a little current of air rising around your body and carrying heat away from you. Scientists call all these currents in fluids *convection currents.* You were studying convection currents in the unit about fire when you learned how a fire gets its supply of fresh air (page 113).

To understand just why fluids circulate when they are heated, you have only to remember what happens to fluids when they are heated and cooled (pages 69-73). Fluids expand when they are heated and contract when they are cooled. Thus, in air or water with a temperature of 70° the molecules are farther apart than they are in air or water with a temperature of 40°. Since this is true, a cubic foot of air or water at 40° weighs more than a cubic foot of air or water at 70°, because at 40° the molecules are

packed closer together. There are more of them in a cubic foot of space; therefore, the air or water is denser, or "heavier."

In your experiments you have seen how warm water and air and cold water and air move. A cubic inch of warm water weighs less than a cubic inch of cold water. Gravity pulls the cubic inch of cold water downward harder than it pulls on the cubic inch of warm water. Therefore, if the cold water and the warm water are next to each other, the cold water moves downward, flows under the warm water, and pushes it upward. The cold water sinks below the warm water; the warm water floats above the cold water. In just the same way gravity pulls downward harder on a cubic foot of cool air than it pulls on a cubic foot of warm air. Because of the greater pull on it, the cold air moves downward and pushes up the warm air.

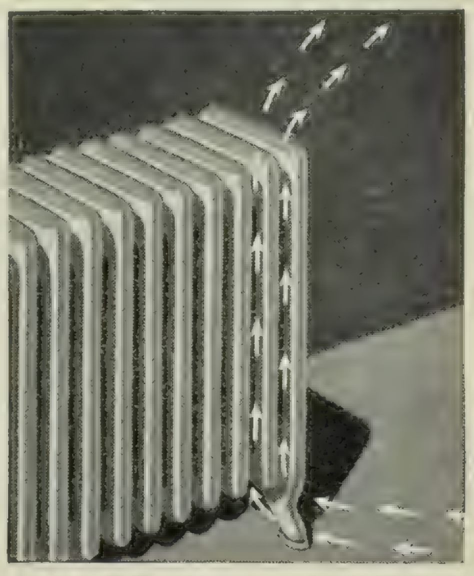

FIG. 181. Convection currents around a warm radiator

But why does the air keep moving upward around a warm radiator or stove? This movement or circulation goes on because a new supply of cool air is constantly being heated. Just as soon as the cool air pushes the warm air up, the cool air itself gets near the hot iron. It gets warm, expands, and becomes less dense. Then the cool air around it can push it up. This happens over and over and keeps the air circulating so long as the radiator is warmer than the air around it (Figure 181).

Transfer of heat by convection is quite different from transfer of heat by conduction. When heat is conducted, it passes from molecule to molecule. When it is transferred by convection, the molecules of heated gas or liquid actually move from one place to another. For example, the molecules of air heated in the furnace move from the basement up into the rooms, taking heat with them. When these heated molecules of air strike the furniture, walls, or objects in the room, they make the molecules that compose these objects move faster. In this way the mole-

cules of heated air pass on some of their heat to the molecules of the objects they strike. When they do this, they warm the objects in the room by conduction.

*Self-Testing Exercises.* In each of the first six exercises you are to decide which word or phrase in parentheses makes the statement correct. In Exercise 1 you are also to supply a word for the blank space.

1. A gallon of warm water weighs (*more*) (*less*) than a gallon of cold water because water ............ when it is being heated.
2. When water is cold, you can get (*more*) (*fewer*) (*the same number of*) molecules into a bottle.
3. The density of hot water is (*greater than*) (*less than*) that of cold water.
4. The density of cold air is (*greater than*) (*less than*) that of hot air.
5. In hot water or hot air the molecules are (*closer than*) (*farther apart than*) in cold air or water.
6. The air around a warm object moves (*upward*) (*downward*), because cold air is (*more*) (*less*) dense than warm air.
7. Tell how the air next to a cold window moves and why it moves as it does.
8. Explain why warm air keeps flowing up from a radiator so long as the radiator is warm.
9. The door of a house is open on a very cold day. (*a*) Does the cold air come in at the top or at the bottom of the door? How do you know? (*b*) Where does the warm air go as the cold air comes in? Use a diagram if it will help.

*Problems to Solve.* 1. John's science teacher told him that he could hold the bottom end of a long test-tube in his hand while he heated the water at the top of the test-tube to the boiling point, but that he could not hold the top end of the test-tube in his hand while he heated the bottom. Is this true? Why?

2. Why is ice placed near the top of a refrigerator instead of near the bottom?

3. Explain why the air in your school-room is warmest near the ceiling.

4. Explain how a burning candle supplies its own fresh air. (See page 113.)

5. Hot-air and hot-water furnaces are always placed in the basement or on the first floor, never on top floors. Why?

6. A tank of cold water and a pipe were arranged as shown in Figure 182. A fire was started around the pipe at A. Soon the tank felt warm at point B. Tell how the heat reached that point from the fire. Be sure to name the method of transfer that took place in each step.

7. When a fire is burning in a fireplace or furnace, there is a strong current of air moving into the fire and up the chimney. This current of air is known as the *draft*. Explain why the air moves up the chimney.

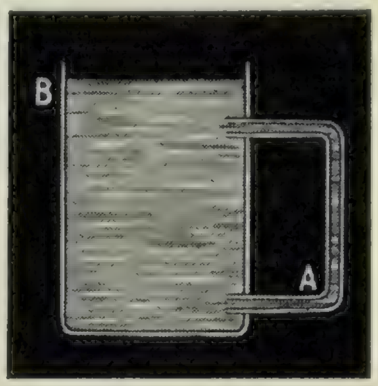

FIG. 182

8. If a room is to be thoroughly ventilated, it is better to open windows at both top and bottom. Explain why.

9. Which would heat a room better, a radiator placed near the floor of the room or one placed near the ceiling? Give the reason for your answer.

10. Draw a diagram to show how you think the currents of water would move in a large pan of water that is being heated in only one spot. Label the cold and the warm water.

11. Why is the draft of air up a chimney stronger after the chimney becomes warm?


FIG. 183

12. A certain kind of Christmas-tree ornament has a little windmill in the top of it. The ornament is balanced on a needle point on top of a light bulb. It turns around as long as the bulb is lighted, but stops when the bulb is turned out (Figure 183). Explain why it does this.

13. The noted French inventor, Claude, needed a supply of cold water from the bottom of the ocean for one of his experiments in Cuba. After he had sunk a pipe, did the water flow up from the bottom, or did he have to pump it up? Tell why.

HOW IS HEAT TRANSFERRED BY RADIATION? The third method of heat transfer is quite different from either conduction or convection. In both conduction and convection heat is transferred by the moving molecules of some material. But, strange as it may seem, heat has a way of travelling where there are no molecules. You can see that the transfer of heat from the sun to the earth cannot be explained by either conduction or convection. The air extends only about 500 miles above the earth.

The remaining distance of over 90,000,000 miles is empty space. In empty space where there is no material (a *vacuum*), there can be no molecules. You know, however, that we do receive heat from the sun. How can you explain this? An experiment will help you see how this takes place.

*Experiment 47.* HOW IS HEAT TRANSFERRED BY RADIATION? Heat an electric radiator (like the one shown in Figure 175, page 275) or a toaster until it glows. If you do not have either of these, a lighted candle may be used. Hold your hand at the side of the flame or source of heat, about six inches from it. Can you feel the heat? The heat that you feel is not coming to you by conduction, because you are not touching the object. It is not reaching you by convection, because a warm current of air is not flowing from the source of heat to your hand. (This may be tested with smoking incense or cork.)

No one knows exactly how radiation takes place. You can, however, get a general idea of what happens in radiation. Any hot object gives out *radiant energy*. This kind of energy is invisible, and it is sometimes called *radiant heat*. As an object becomes hotter and hotter, it gives out more and more radiant energy. This energy travels in straight lines through space, but this radiant energy or radiant heat is not true heat. You can see that if it were really heat, the air high above the earth would be warm, because it is nearer the sun than the lower air. But, as you know, the tops of high mountains are cold, and aviators must wear heavy clothing if they go very high.

But this radiant energy that travels through space can be changed to heat energy. When radiant energy strikes materials than can absorb it, it sets the molecules of the material in more rapid motion. Thus the radiant energy is changed into heat energy.

*Experiment 48.* HOW IS RADIANT ENERGY CHANGED TO HEAT? Take two test-tubes and partly cover one of them with smoke by rotating it in a candle flame. Place the two tubes in an upright position and nearly fill the tubes with water. Take the temperature of the water in each tube and record the readings. Now bring the tubes into the direct sunlight and leave them there for fifteen minutes. Again take the temperature of the water and record the readings. What do the results show?

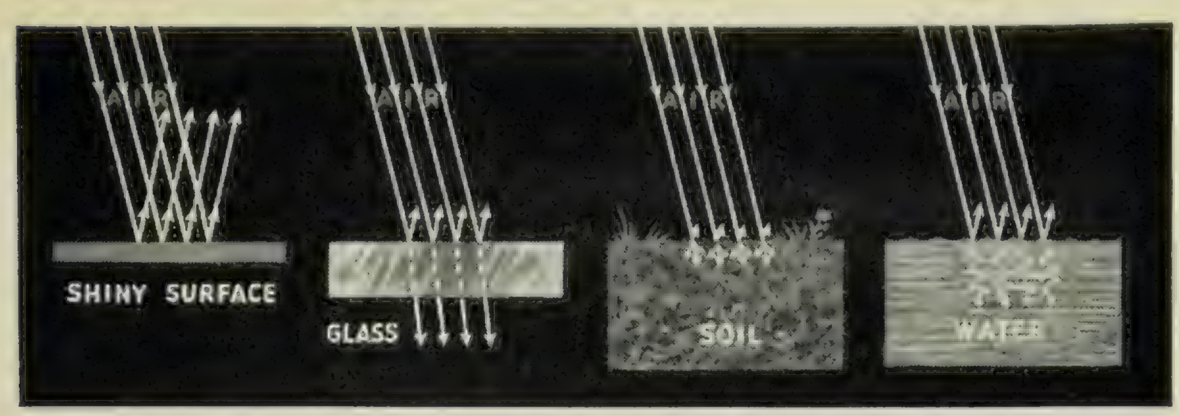


FIG. 184. In general, dark-colored materials *absorb* much radiant energy. Light-colored and "shiny" surfaces *reflect* the radiant energy without changing it to heat; therefore they are warmed very little when radiant energy strikes them. Many substances, like glass and air, that allow light to pass through them, also allow radiant heat to pass through them without absorbing much of it.

In a clear test-tube the temperature of the water rises much less than in a blackened tube. This happens because the blackened tube absorbs a great deal of radiant energy, changes it to heat, and the heat warms the water. The clear tube absorbs less of the radiant energy than the black tube. Study Figure 184 carefully, and read what is said below it.

Now you can see why the air is not warmed very much by the sun. The air absorbs very little of the radiant energy; therefore very little of it is changed to heat by the air. You can also see why you are warmed if you stand in front of a sunny window on a cold day. The window glass lets the radiant energy pass through without absorbing it. If you touch the window-pane, you find that it is cold. When the radiant energy passes through the glass and strikes your face or clothes, it is absorbed and changed to heat energy. Then you get warmer.

You can now understand why transfer of heat by radiation is different from transfer of heat by conduction and convection. No molecules are needed to transfer the heat. Energy is transferred from the fire or sun or stove by the radiant energy that they send out. This energy passes through transparent materials, such as air and glass, without warming them. But when the radiant energy is absorbed by some material and is changed into heat energy, then it sets the molecules of the material moving faster, and the material gets warmer.

FIG. 185. The glass bottle, seen at the left, has double walls, as shown in Figure 186. The space between the walls is a partial vacuum.

*Self-Testing Exercises.* 1. Tell in your own words how you are warmed when you stand in front of an open fire.

2. What is wrong with this statement? *Radiation is heat.* Change the statement to make it correct.

3. How is the transfer of heat by radiation different from conduction and convection?

*Problems to Solve.* 1. Give three original examples (ones that are not given in a book, but ones that you have observed) of objects being warmed by conduction, three examples of heat transferred by convection, and three examples of objects being warmed by radiation.

2. Is this statement true? *Radiant energy from the sun passes through the space between the earth's atmosphere and the sun without warming the space.* Explain why you believe your answer correct.

3. Can a red-hot stove heat materials by conduction, convection, and radiation? Explain.

4. On a sunny day snow melts faster where it is dirty or under dead leaves than where it is clean or in the open. Explain.

5. In hot countries the people wear white clothes. Why are these cooler than dark clothes?

6. Figures 185 and 186 show how a vacuum bottle is constructed. Such a bottle keeps hot coffee too hot to drink for several hours. It also keeps cold things cold just as well.

*a*) How does the vacuum between the two glass walls help keep the coffee hot?

*b*) How could heat get across the vacuum? In a reference book find how that method of heat transfer is prevented.

c) Why is a cork instead of a metal stopper used?

*d*) Why will the vacuum bottle keep things cold as well as hot?


FIG. 186

7. Plan and carry out an experiment to find how rapidly hot water loses heat in a vacuum bottle.

## ⸿ 2. What happens to heat when a material changes from one state to another?

IF YOU HAPPEN TO LIVE, or ever have lived on a farm, you may have seen your father do a curious thing. You may have seen him place a tub of water in the cellar to keep the vegetables stored there from freezing on a cold winter night. The curious part about this is that when the water in the tub freezes, it keeps the air in the cellar warm. Florists may wrap flowers in many layers of wet newspaper when the flowers are to be shipped long distances in freezing weather. The paper may freeze, but the flowers will not freeze until long after the paper has frozen. Do you know how water keeps objects around it warmer while it is freezing?

When you go swimming on a hot, sunny day, you have probably noticed that if you sit on the beach, you get very hot. But if you go into the water and get your skin and bathing-suit wet, you can sit in the hot sun and feel quite cool until your skin and bathing-suit dry. The sun is just as hot as it was before you got yourself wet, but you feel cooler so long as you are wet. Why is this true?

A certain thing is true about each example in the two paragraphs above. In each case a change of state takes place. When water freezes, it changes from a liquid to a solid. When ice melts, it changes from a solid to a liquid. When your bathing-suit dries, the liquid water changes to a gas. To explain these examples and many other things that happen around you every day, you will have to discover what happens to heat when a material changes from one state to another.

WHY DOES ICE COOL THINGS WHEN IT MELTS? On a hot summer day we often put some ice in a glass or a pitcher to make ice-water. When the ice is added, some of it melts, and the water is cooled until it is at about the freezing temperature. If you place the pitcher in the sun, the water still remains at about the same temperature until all the ice is gone. Now you know that the radiant energy from the sun is giving heat to the pitcher of water, yet the water does not get any hotter until all the ice is melted. Why is this true?

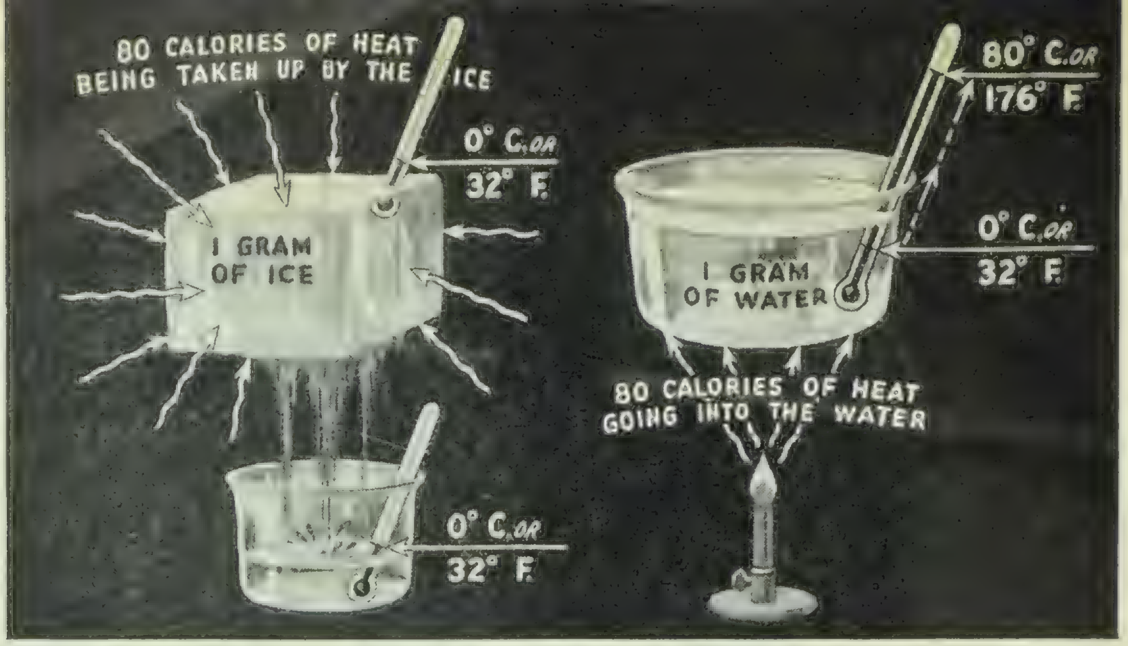


FIG. 187. Scientists measure heat in *calories*. A calorie is the amount of heat required to raise the temperature of one gram of water one degree centigrade. Careful experiments show that it takes about 80 calories of heat to melt one gram of ice, and the water to which the ice changes stays at the same temperature as the ice. But when you put 80 calories of heat into the gram of water, the water gets so hot that it will burn your hand. Be sure that you can explain everything in this drawing.

*Experiment 49.* WHAT HAPPENS WHEN A MIXTURE OF ICE AND WATER IS HEATED? Fill a beaker two-thirds full of crushed ice. Place the beaker over a wire gauze on a ring stand. Heat the beaker with a low flame. Stir the contents of the beaker constantly and take the temperature of the water from time to time until the ice is all melted. Does the water get hotter and hotter, or does it stay cold until all of the ice is melted?

Experiment 49 gives you something to think about. Ordinarily when you heat water, it gets hotter. In this case the water did not get much hotter when it was heated until after all of the ice was melted. This raises an interesting question: What became of the heat before the water began to get warmer? The only satisfactory explanation is that the heat was being used to change the ice into water without warming the water at all.

Experiment 49 shows clearly that heat is really a form of energy. Energy is what makes things happen to matter. It makes changes take place in matter. Usually heat seems to warm things. In this experiment heat changes ice to water without warming it. This happens because energy is needed to pull the molecules of the solid apart so that it may change to a liquid. To melt one gram of ice takes 80 calories of heat. This much heat will raise the temperature of one gram of water 80 degrees. You can see, now, why ice cools water. The heat required to melt the ice comes

from the water. Ice uses more heat in melting than does almost any other solid; therefore ice is a good "cooler."

As you might expect, when water changes to a solid, it must give up heat. Experiments show that one gram of water will give out 80 calories of heat when it changes from a liquid to a solid. Does this help explain why farmers sometimes put tubs of water in the cellar where they store vegetables during the winter?

*Self-Testing Exercises.* 1. Explain why ice is a good material to cool liquids.

2. What work is heat energy doing while ice is melting?

3. Why will a pound of ice cool a pitcher of water more than a pound of ice-water will cool the water in the pitcher? Keep in mind that both the ice and ice-water are at 32° F. or 0° C.

4. Turn to Figure 187, cover the explanation beneath the drawing, and then write your own explanation of what the drawing shows.

*Problems to Solve.* 1. We use ice in refrigerators to keep our food cool. Some people cover the ice with blankets or paper to keep it from melting. Will this keep the food as cool as it would if the ice were allowed to melt? Explain.

2. Near a large body of water in which ice is melting the temperature of the air is cooler than it is at a place one hundred miles inland from the body of water. Explain.

3. Plan an experiment to show that a pound of ice will cool water more than a pound of ice-water.

4. Why do snow and ice melt slowly in the spring?


FIG. 188. Ice cools objects because heat passes from the warm objects to the cold ice.

5. How do layers of wet paper wrapped around flowers in freezing weather keep the flowers from freezing?

WHAT HAPPENS TO HEAT WHEN A LIQUID EVAPORATES? If you place a drop of alcohol or ether on your hand and let it evaporate, a curious thing happens. The spot on your hand from which the liquid is evaporating gets cold. Now you know that when anything gets cold, heat is being taken away from it.

FIG. 189. Apparatus for Experiment 50

Apparently, heat is taken from your hand when the ether evaporates. Let us try an experiment to see if this guess is true.

*Experiment 50.* DOES AN EVAPORATING LIQUID TAKE HEAT FROM THE THINGS AROUND IT? (*a*) Let a stoppered bottle of ether, alcohol, or water stand in your room for several hours so that it will be at room temperature. Get a one-holed stopper that will fit the bottle and push a chemical thermometer through the hole. Tie a piece of thin cloth or a thin layer of cotton about the bulb of the thermometer. Remove the regular stopper from the bottle and put the stopper and thermometer into the bottle so that the bulb is in the liquid. Have the stopper fit tightly.

After a few minutes read the thermometer. With another thermometer take the temperature of the air in the room. How do the two temperatures compare?

*b*) Without removing the stopper from the bottle, slide the thermometer upward so that the bulb is above the liquid. After a few minutes read the thermometer. Is there any change in the temperature? Is the liquid on the bulb of the thermometer evaporating?

*c*) Now remove the thermometer and stopper from the bottle and hang them up. Watch the mercury in the thermometer. How low does it go? Is the liquid evaporating?

*d*) If you are using water, fan the thermometer. What effect does this have upon the temperature?

*e*) If possible, repeat the experiment with one of the other liquids named in the directions and compare the results. Explain any differences you find.

Your experiment showed you that so long as the thermometer was inside the bottle, where no evaporation could take place, the temperature remained the same as that of the room. As soon as

the thermometer was brought into the air, the temperature dropped. When the thermometer was fanned, the temperature dropped still farther.

What happened in your experiment is somewhat similar to what happens when a solid changes to a liquid. Heat is required to change a solid to a liquid. Heat is also required to make the liquid change to a gas. The heat comes from the things around the evaporating liquid. When a drop of water or of alcohol evaporates from your hand, heat is taken from your hand. When water evaporated from the thermometer, heat was taken from the mercury in the thermometer. Fanning the thermometer caused the water to evaporate faster. Heat was taken more rapidly from the mercury, and there was a greater cooling effect. If alcohol or ether is used, the cooling effect is much greater than with water because alcohol and ether evaporate very much more rapidly than water.

Now you can see how evaporation causes cooling. If evaporation is slow, there is little cooling. If it is rapid, a great deal of cooling may take place. With ether and other liquids the temperature may even go below the freezing temperature of water.

The cooling effect of evaporation is used to tell how much moisture there is in the air. The instrument used, called a *wet-and-dry-bulb thermometer* (Figure 190), consists of two thermometers. One thermometer has a piece of cloth around it. This cloth is either dipped in water when a reading is to be taken or is kept wet by having the lower end of the cloth in a small bottle of water. The amount of moisture in the air is known as the

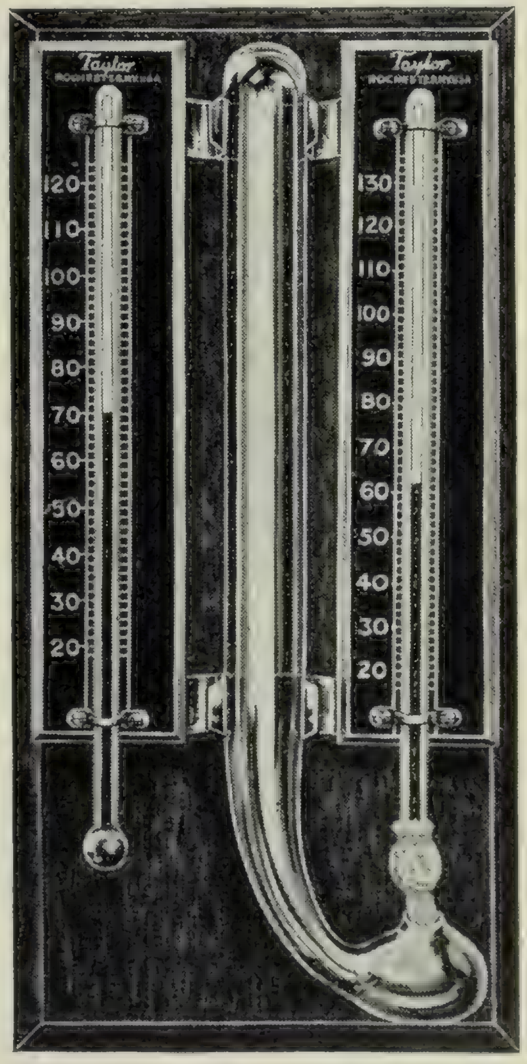


FIG. 190 (Taylor Instrument Companies photo)

*humidity.* The humidity of air can be measured by a wet-and-dry-bulb thermometer because evaporation is more rapid when the air is dry. When the evaporation is more rapid, the wet-bulb thermometer is cooled more. If the air is quite moist, there will be little evaporation, and the wet-bulb thermometer will read almost the same as the dry-bulb. When the air becomes completely full of water vapor, evaporation of water stops. Then the two thermometers read the same.

As you learned in Unit 3, evaporation takes place at all temperatures, but as a liquid becomes hotter, it evaporates more rapidly. When it is heated enough, it boils. When water is first heated, the temperature continues to rise until it reaches the boiling temperature. After steam has begun to form, the temperature of pure water goes no higher, no matter how hot the fire is or how long you boil the water. What do you suppose happens to this heat? It is used in changing the water into steam. To change one gram of boiling water to steam takes 539 calories of heat. This heat makes the molecules fly farther apart. The molecules fly so far apart that a cubic foot of water makes 1600 cubic feet of steam. The heat energy does the work that is necessary to bring about this change from a liquid to a gas.

*Self-Testing Exercises.* 1. Why does a wet-bulb thermometer usually show a lower temperature than a dry-bulb thermometer?

2. How wet is air when a wet thermometer and a dry one show the same temperature? How do you know?

3. A boy went in swimming on a warm summer day when the air and the water were both the same temperature. He shivered whenever he got out of the water. Explain why.

4. If you draw your breath quickly through your partly opened mouth, your tongue feels cool. Why is this?

*Problems to Solve.* 1. Suppose that the thermometer stands at 99° F. and the air is full of water vapor. On such a day can you cool yourself by fanning yourself?

2. In some hot, dry countries the drinking water is kept in the shade in porous bags or in porous earthenware jars. Enough water seeps through these bags and jars to keep the outside surface slightly moist. Will the water inside be warm or cool? Why?

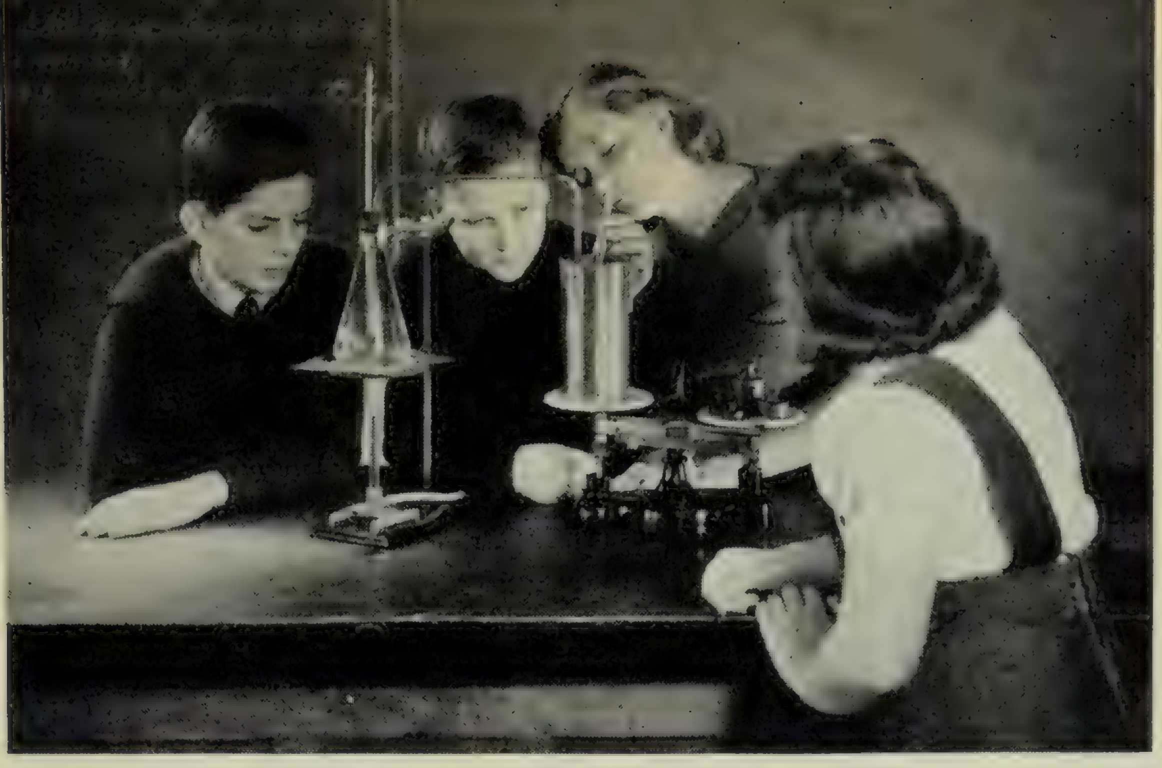

FIG. 191. Apparatus for Experiment 51

3. Some days in summer seem very warm, and our skins are kept wet with perspiration even though the thermometer says it is no warmer than other days when we are quite comfortable. Why do we feel so differently?

4. Explain why a fan makes us more comfortable on a day when the temperature is 100° F.

5. *Dry ice* (solid carbon dioxide) is a solid that evaporates without melting. As it evaporates, it keeps itself at a temperature of about —109° F. until it is gone. Why does it stay so cold?

6. After water has begun to boil, will potatoes cook more quickly with a high fire than with a low fire? Explain.

WHAT HAPPENS WHEN VAPOR CONDENSES? Your mother has probably told you that a burn from steam is worse than a burn from boiling water. Can this be possible? If so, why? The following experiment will help you answer the questions.

*Experiment* 51. WHICH WARMS THINGS MORE, BOILING WATER OR STEAM? (*a*) Place a can containing at least 300 cubic centimetres of cool water on the left side of a pair of balances. Balance the can and the water. Then add 30 grams in weight to the right side. Take the temperature of the water. Take the temperature of the steam in a flask above some boiling water. Pass live steam from the flask through the tube into the can of water until enough steam has condensed to balance the added weights. Take the temperature of the water again.

*b*) Empty the can and put in the same amount of cool water as before (300 cubic centimetres). Take the temperature of some boil-

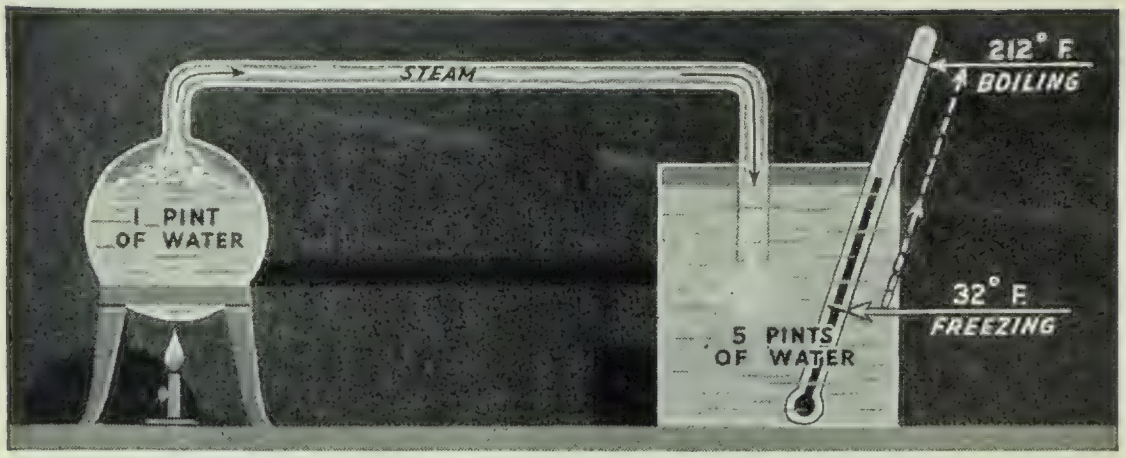


FIG. 192. Study this drawing carefully. It will help you to understand what is said on this page. Be sure that you can explain the drawing.

ing water. Then pour 30 grams of boiling water into the can. How much does it warm the water in the can?

How did the temperature of the steam compare with the temperature of the boiling water? Which one warmed the cold water more? How much more? Why?

You remember what you learned about evaporating water. It cools things because each gram that evaporates takes a certain amount of heat. This heat causes the molecules to move much faster. What would you expect when steam or water vapor changes back to a liquid? The molecules must be slowed down. In other words, the heat that was required to change the liquid to a vapor must be taken out of the vapor again.

In your experiment you found that steam heated the cold water much more than boiling water heated it, even though the boiling water was the same temperature as the steam. Enough heat comes out of each pint of condensed water to heat more than five pints of water from freezing to boiling! The heat that comes out of a pint of water when it condenses would heat thirty pounds of lead to its melting point and melt it. When steam changes to water, each gram gives out 539 calories of heat.

The immense amount of heat taken in when water evaporates or changes to steam is of great importance to anyone who evaporates water, condenses water vapor, or handles steam. Whenever water is heated to change it into steam, very large amounts of heat are required. Then when the steam changes back to water, the heat comes out of it. That is one reason why steam-heating

plants can be made very effective. Water takes up a great deal of heat in the boiler where the fire is. This heat changes the water to steam. As steam, it can be sent through pipes very rapidly for long distances. When the steam is cooled in the radiators, it condenses and gives out its great store of heat to warm the rooms.

*Self-Testing Exercises.* 1. Why is a burn from steam worse than a burn from an equal weight of boiling water?

2. The steam that enters a radiator may be practically the same temperature as the water that leaves the radiator. How, then, has the room been warmed by the radiator?

*Problems to Solve.* 1. When water must be freed from minerals, it is distilled, that is, it is changed into steam and then condensed in another vessel. Why is this process expensive and slow?

2. Water in the form of steam is sent into the radiators of one room to warm it. Hot water is sent into the radiators of another room of the same size as the first. Which room will require more pounds of water to warm it? Explain.

3. When does a vapor get the energy that is given out at the time the vapor condenses?

## ❡ 3. How do we keep our buildings warm?

How does a stove heat a room? It is pleasant to go into a well-heated room on a cold winter day. We do not roast on one side and freeze on the other; the air is not too dry; there are no unpleasant odors; and we do not have to open and close windows constantly to keep the room comfortable. Let us see how the principles of heat transfer and of evaporation and condensation are used to make our homes and other buildings so comfortable in cold weather.

A fireplace is one of the simplest ways of heating a room, but it is not very efficient. The heat from the fire warms the air in the fireplace and the chimney. A convection current then moves up through the chimney. Unfortunately, this current carries much of the heat outdoors. The heat that warms the room must be transferred by radiation. Radiant energy goes out into the room from the fire, warming the walls, the furniture, and other objects. These warm objects then give heat to the air by conduction.

Metal stoves placed in convenient positions in rooms cost little and are very efficient heating devices. The heat from the fire passes through the walls of the stove by conduction and heats the air around the stove. This warm air is pushed up by the heavier cool air from other parts of the room. In this way the hot stove sets up convection currents that carry the heat to all parts of the room. Stoves also heat by radiation. You may have believed that only glowing, or *luminous*, things, like the sun or a fire radiate energy. However, almost every object sends out radiant energy. An object may not feel hot, but if it is warmer than things around it, it will lose heat energy to them by radiation.

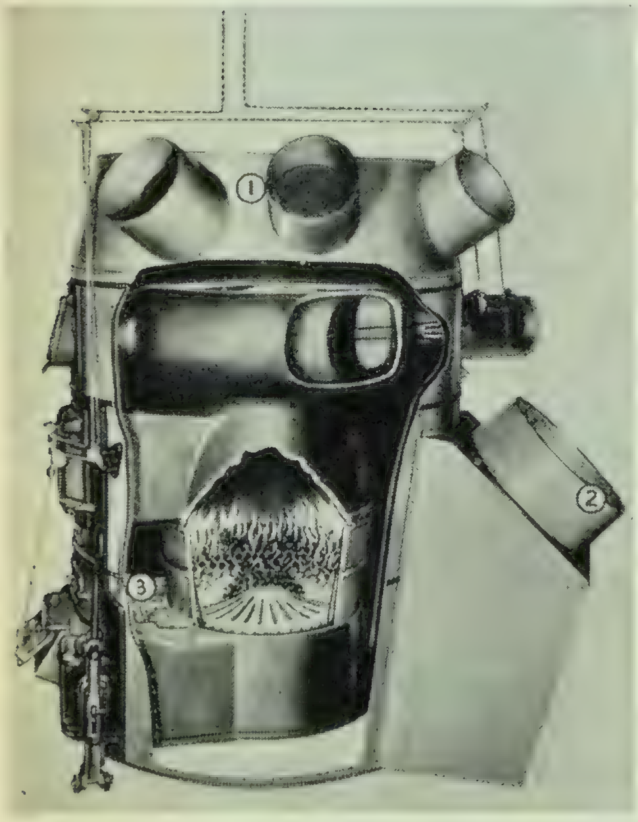

FIG. 193. A modern hot-air furnace. (1) Openings for hot air ducts. (2) Opening for cold-air duct. (3) Water pan to humidify the warm air (Holland Furnace Co. photo)

HOW DO HOT-AIR FURNACES HEAT OUR BUILDINGS? Stoves, or heaters, as they are often called, take up much space, have to be cleaned and refuelled often, cause considerable dirt, and are liable to cause fires. As you can readily see, it would be much more convenient to have one source of heat for all of the rooms in a house rather than a separate fireplace or stove for each room. This convenience is supplied by our modern furnace.

A hot-air furnace is really a large stove in which the *fire box* is surrounded by an outer *jacket* filled with air (Figure 194). This jacket is connected with the rooms above by pipes, or *ducts*, that lead to openings in the floors or walls of the rooms. These openings are covered with metal gratings called *registers*. Many hot-air systems have cold-air pipes, or *returns*, that carry the air back to the furnace again. In heating systems of this type the warm-air register is on one side of the room, and the cold-air register is on the other side of the room, as you can see in Figure 194.

When the air in the jacket of the furnace is heated, a convection current is produced. The cold air in the room sinks through the cold-air register and pushes the lighter and warmer air up through the warm-air ducts. The hot air passes across the top of the room and is cooled. It sinks on the opposite side of the room and goes down through the cold-air register. In this way there is a complete circulation of the air. Sometimes a fan is added to make the air circulate more rapidly.

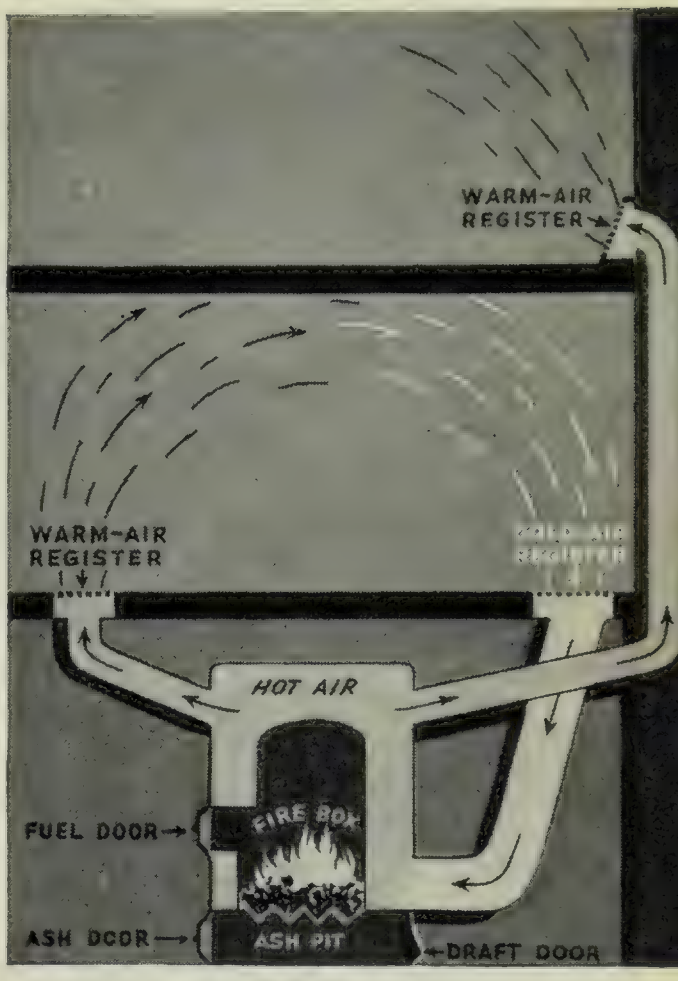


Fig. 194. How a hot-air heating system works

Some hot-air systems have no cold-air return to the furnace. A pipe from the outside brings fresh air into the bottom of the jacket around the fire box, and this air is warmed and circulated. This type of furnace requires more fuel than the type in which a cold-air return is used, because the cold air entering from the outside must be heated. It has the advantage, however, of sending fresh air to all the rooms and thus securing better ventilation.

The hot-air heating system is probably the most commonly used central-heating system in homes. It has many advantages. It is simple to install and costs less than other types of heating systems. The air is heated quickly, so that the furnace begins to heat the house almost immediately. Moisture is easily added to the hot air by a water pan in the furnace. However, the hot-air furnace has some disadvantages. It is rather hard to keep an even temperature throughout the house at all times. A strong wind may make one side of the house cold and the other side too warm. Another disadvantage of a hot-air furnace is that a small crack in the fire box may let smoke and poisonous gases go up to the rooms. But this is not likely to happen. A good hot-air system heats a small home very cheaply and satisfactorily.

How does a hot-water heating system work? The hot-water heating system supplies heat to the rooms of a building in much the same way as the hot-air system. The fire box of a furnace is surrounded by a *water jacket*, or boiler, filled with water. The water also fills two sets of pipes connected with a *radiator* in each room. When the water in the boiler is heated, cool water in one set of pipes pushes the hot water up the other pipes to the radiators. Each radiator is made of hollow metal pipes arranged to expose a great deal of surface to the air. Heat is conducted from the water through the metal of a radiator and into the air that touches the metal. Convection currents are immediately set up in the air, and the heat is distributed to all parts of the rooms.

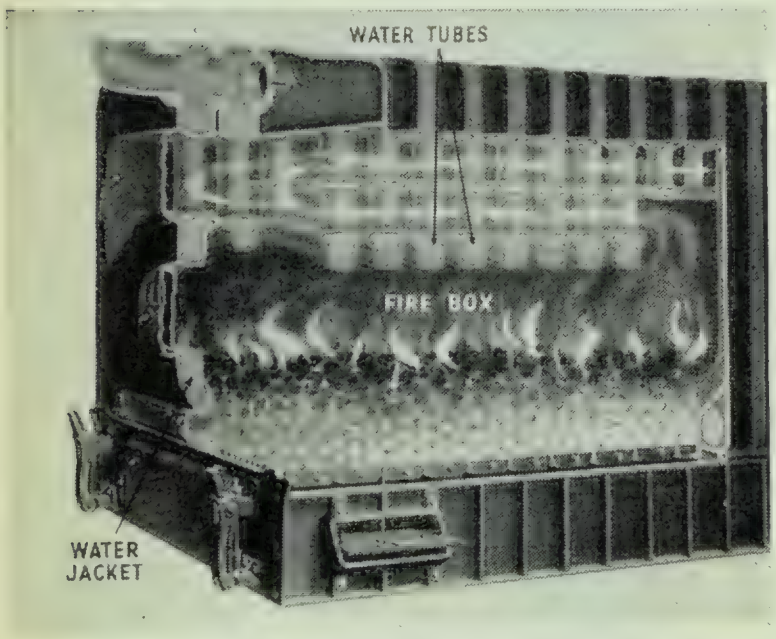


Fig. 195. Cut-away view of a hot-water furnace. Part of the water jacket is made of tubes so that more of the water can come in contact with the hot metal of the jacket.

As the water in the radiator gives out its heat and becomes cool, it sinks through the return pipe and enters the boiler again. Do you see that two important convection currents heat each room: (1) the current of water inside the pipes and radiators and (2) the currents in the air of the room?

Hot-water systems have one special feature that other systems do not have. If you should start a fire in a closed hot-water system full of water, expansion of the water would burst some part of the system. Some device must be used to prevent this kind of accident and yet keep the pipes all full of water. The usual device for this purpose is an *expansion tank* placed above the highest radiator in the system (Figure 196).

The hot-water system has certain advantages. It keeps the temperature fairly even in all the rooms, and the heating plant is quite easy to operate. It begins to warm the rooms more quickly

than steam, but it warms them more slowly than the hot-air system. It is economical of fuel, because once the water is heated, only a small fire is needed to keep it hot and circulating. The pipes and the furnace take up much less space than do those of a hot-air heating system. Perhaps the greatest disadvantage of the hot-water system is that it costs so much to install. It is also necessary to provide a separate ventilation system. If the fire is allowed to go out for some time during the winter, the pipes must be carefully drained of water. If water is left in the pipes, it may freeze. When it freezes solid, it may expand enough to burst the pipes.

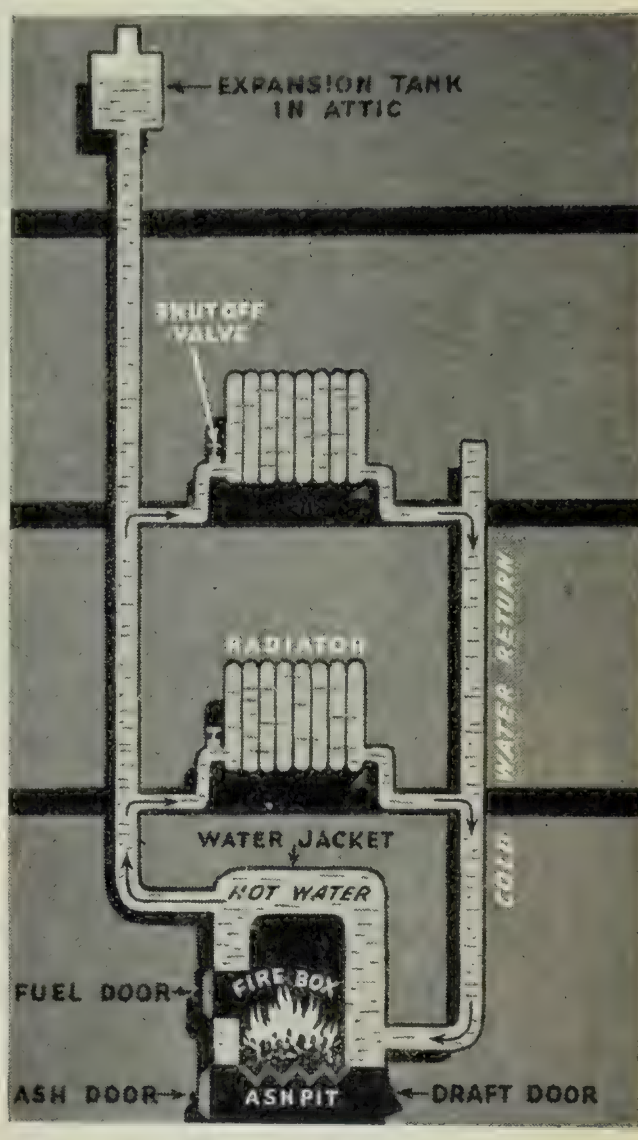


Fig. 196. How a hot-water heating system works. Be sure that you can explain everything in this diagram.

**How does a steam-heating system work?** The construction of a steam-heating system is very much like that of a hot-water system. The water is heated in a water jacket or boiler around the fire box. However, the boiler is only partly filled with water. The heat from the fire changes the water to steam, and the steam is forced upward through the pipes and to the radiators. In the radiators the steam condenses. As you know, when the steam condenses, it gives up the very large amount of heat that was needed to evaporate the water in the boiler. This heat warms the metal of the radiators, and the radiators warm the rooms.

The condensed steam then passes down through a pipe back to the boiler, where it is again changed to steam. In "one-pipe" steam systems the water returning to the boiler leaves the radiator through the same pipe used to bring the steam to the radiator. In other systems there are separate pipes for steam and water.

Steam-heating systems require several special devices to make them work successfully. Each boiler must have a *safety valve* to

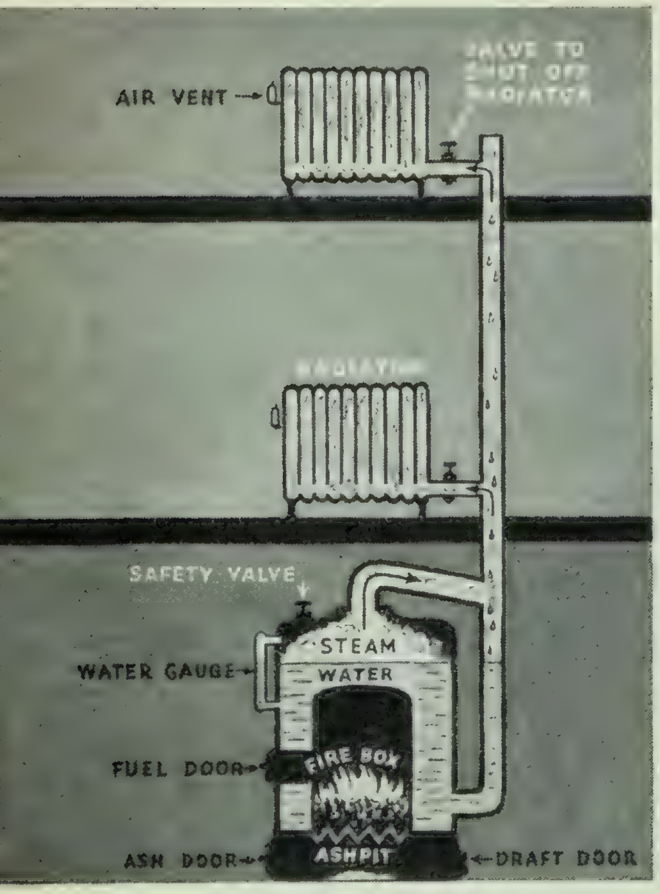


FIG. 197. How a steam-heating system works

let steam out if for any reason the pressure becomes too high (Figure 197). A *water gauge*, or "water glass," is always used to show how high the water stands in the boiler. If the water gets too low, the boiler will be seriously damaged. Steam radiators usually must have *air vents* to let the air out so that the steam can come in. These devices contain a special valve operated by heat. So long as cool air is escaping, they remain open. But when the hot steam reaches them, they close and keep it in.

Steam-heating systems are commonly used in large buildings, because the pressure of the steam forces the steam rapidly through the pipes and radiators. The result is that rooms a long distance from the furnace may easily be heated. The cost of installing a steam-heating system is higher than that of a hot-air heating system, and a steam system does not, itself, provide a method of ventilating the rooms.

*Self-Testing Exercises.* 1. Why is a stove more efficient than a fireplace in heating a room?

2. In what ways is a hot-air system like a hot-water system? In what ways is it different?

3. Why do the radiators of a steam-heating plant get hotter than the radiators of a hot-water heating system?

4. If you were going to build a house, what kind of heating system would you choose? Why?

*Problems to Solve.* 1. Of all the heating systems described in this book, which one radiates no heat into a room?

2. What kind of heating system is most common in your community? What are the reasons for its use there?

3. A convection current is necessary for the working of every common heating device that uses fire. What does this current do in each device?

4. Find out about vapor, vacuum, or low-pressure heating systems. What is the advantage of this type of system?

5. Find out about different kinds of hot-air furnaces. What are the advantages of each type?

6. Find out how thermostats regulate temperature.

HOW CAN THE HEAT BE KEPT IN OUR BUILDINGS? You have learned how good conductors with special arrangements of pipes and other devices are used to transfer heat from fires to the rooms where you live. It is almost as important to know how to keep the heat inside our homes. Houses are made much more comfortable when we apply our knowledge of heat transfer to the problem of preventing the escape of heat from the house. In addition, the cost of heating the house is lowered.

Heat can escape from our buildings in three ways: (1) It can be conducted through walls, windows, and roofs. (2) It can be carried out of the house with the air that passes through porous walls and through cracks around windows and doors. (3) It can be radiated through windows. To reduce these losses of heat we can do several things. Cracks around window and door casings should be filled. Special putty-like materials are sold for this purpose. "Weather-strips" made of metal or felt and placed around window-sashes and doors are also a great help. Next in importance is the use of extra windows, or storm windows, outside the regular windows. A great deal of heat is lost by conduction through glass. Two windows with an air space between them greatly reduce this heat loss.

The last important way to keep heat in our buildings is to use good insulating materials, or non-conductors, in the walls and under the roofs. The walls of wooden houses are usually double with air spaces in them. Such houses are made much warmer in winter if these spaces are filled with good insulation, such as mineral wool. A layer of good insulation between the ceiling and roof of almost any building also helps to reduce the loss of heat by conduction. Insulation is also valuable in

FIG. 198. The window at the right is ready for winter with its storm window in place.

FIG. 199. Through his knowledge of heat control man has learned how to keep his buildings cool in summer and warm in winter. This workman is putting material in the walls of a house to insulate the house, that is, to keep heat from passing through. (General Insulating photo)

summer because the heat is kept from passing through the walls so quickly, and the house is cooler. Insulated attics are especially helpful in keeping upstairs bedrooms cool.

*Self-Testing Exercises.* 1. State the three ways in which heat is lost from poorly constructed buildings.

2. What are the most important ways of preventing loss of heat from a home? Explain why each one helps.

*Problems to Solve.* 1. Examine your own home and decide whether the heat loss is serious in cold weather.

2. What are common insulating materials made of, and why are they non-conductors of heat? Watch for advertisements and prepare an exhibit of different kinds of insulation.

3. How would the addition of storm windows to a house make the air warmer near the floor? Draw a diagram to show how it would affect the convection currents in the room.

4. Why are basement rooms usually the coolest rooms in the house during hot weather?

## ¶ 4. How do we keep things cool in warm weather?

IN WARM WEATHER MANY KINDS OF FOOD and many drinks are much more appetizing if they are cold. In such weather we also like to have the air in our buildings cool. But it is even more important that foods such as milk and meat be kept from spoiling. The bacteria and other living things that cause milk to sour

and fresh meat to decay grow very rapidly at summer temperatures. Therefore these foods must be used up quickly unless there is some way to keep them cool. If foods can be kept at a temperature of 40° F. and lower, the bacteria that cause them to decay cannot grow.

For a long time the only practical way to keep food cool was to use cool cellars, cool water from wells and lakes, and ice from lakes and streams. These methods are still used in many country homes. However, many years ago machines for making ice were invented. The artificial ice made by machines had so many advantages that it soon took the place of natural ice wherever it could be made. Today great refrigerating and cold-storage machines are found in almost every town or city of any size. And every home that is supplied with electric current may have a small electric refrigerator to keep food cool and even to make small amounts of ice. Homes without electricity may have refrigerators that burn kerosene oil or illuminating gas to keep them cool! How can these things be done?

HOW CAN ICE BE MADE IN A WARM PLACE? In order to make water freeze in warm weather or to make the inside of a box or room cool, something must be done to get heat out of the warm material. We must either make the heat disappear, or in some way move it out. Can you imagine how a machine can do this? Probably you know that ice-cream is frozen by putting a mixture of ice and salt around a can that contains a mixture of cream and other materials. Of course, water could be frozen in the same way, but you would need ice to start with. You can make a little ice for yourself without having anything cold to start with. To do this you need to use evaporation.

*Experiment* 52. HOW CAN ICE BE MADE BY EVAPORATION? Put three or four drops of water in the centre of a large flat cork. On the water place a thin, concave glass dish known as a "watch glass." The experiment will work best if the watch glass is at least three inches in diameter. Set the cork and dish in a well-ventilated place away from any flame. Fill the dish almost full of ether. Fan the ether vigorously with a piece of cardboard or a folded newspaper.

When the ether has almost evaporated, you should see a ring of frost on the under side of the watch glass. Lift the watch glass by

the edge. Why does the cork stick to the glass? Explain what has happened. You may be able to understand better what happened if you repeat the experiment while someone holds the bulb of a chemical thermometer in the evaporating ether and calls out the temperature from time to time.

You know from Problem 2 that much heat is required when a substance evaporates. Ether evaporates much faster than water. Fanning the ether drives the ether vapor away and helps the liquid evaporate even faster than it would without fanning. This rapid evaporation takes heat out of the liquid ether until its temperature is below 32° F. The warmer water gives up its heat by conduction through the watch glass into the ether until the water freezes.

The ether and the dish in this experiment really formed a small ice machine. However, you can see that ice made by this plan would be very expensive. The ether or other liquid used to lower the temperature is evaporated and lost. Let us see how scientists have solved the difficulties of making things very cold by what they have learned about the evaporation of liquids.

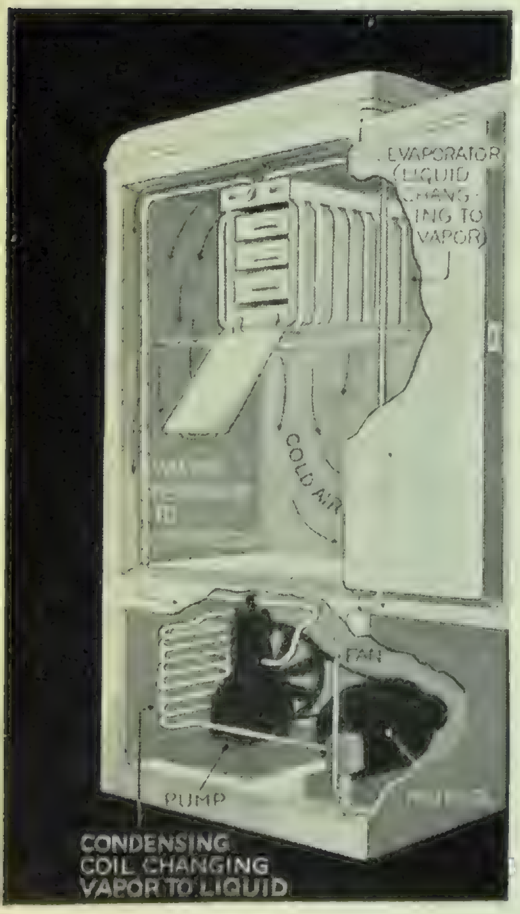


FIG. 200

HOW DO REFRIGERATING MACHINES WORK? To find out how artificial cooling machines work, we will examine an electric refrigerator. The pipes in the refrigerator (Figure 200) contain a gas, such as sulphur dioxide, which can be easily changed to a liquid if it is compressed. This compression is done by a pump, or *compressor*, which is operated by an electric motor.

The compressed gas is then forced into the *condensing* coils. When the gas is compressed, heat is given off, and the pipes of the coils become warm. This heat must be carried away before the gas will condense to a liquid. A fan attached to the motor blows the warm air away and brings cooler air to take up more heat and cool the coils. The condenser pipes are coiled so that more surface can be exposed to the air. As a result, the gas is changed to a liquid.

Fig. 201. A modern ice-making plant. The floor is really tops of cans full of water and partly submerged in a solution of salt and water. Nine of these cans are seen pulled up out of the salt water. In the background is the machinery that compresses the vapor, keeps a partial vacuum in the vaporizing pipes, and in other ways operates the plant. (Westerlin and Campbell photo)

The liquid sulphur dioxide is then forced into the cooling unit, or *evaporator*. This is a box-like part inside the refrigerator near the top and surrounded by coils of pipe containing the sulphur dioxide. In these pipes the pressure is low, and the liquid sulphur dioxide changes back to a gas or vapor again. The heat required for this change is taken from the air and water in the cooling unit. The water in the ice trays is then changed to ice. As fast as the vapor is formed in the evaporator, it is removed by the pump or compressor. It is the removal of the vapor that keeps the pressure low in the evaporator and allows the liquid to change to a vapor. The compressor, as you see, has two purposes: It removes vapor from the evaporator, and then it compresses back into a liquid the vapor that is removed. In Figure 202 you can see how it operates.

This process of compressing into a liquid and evaporating into a gas takes place over and over again. A thermostat turns the current on for the motor when the temperature in the ice-box rises to a certain point. It also turns off the current when the ice-box is sufficiently cooled. Most ice-boxes have regulators that can be set to make the box colder or warmer.

In an ice factory or a cold-storage plant liquid ammonia is commonly used. The evaporation of the ammonia cools a concentrated solution of salt, or calcium chloride, called *brine*. Since a solution freezes at a lower temperature than water, the brine can

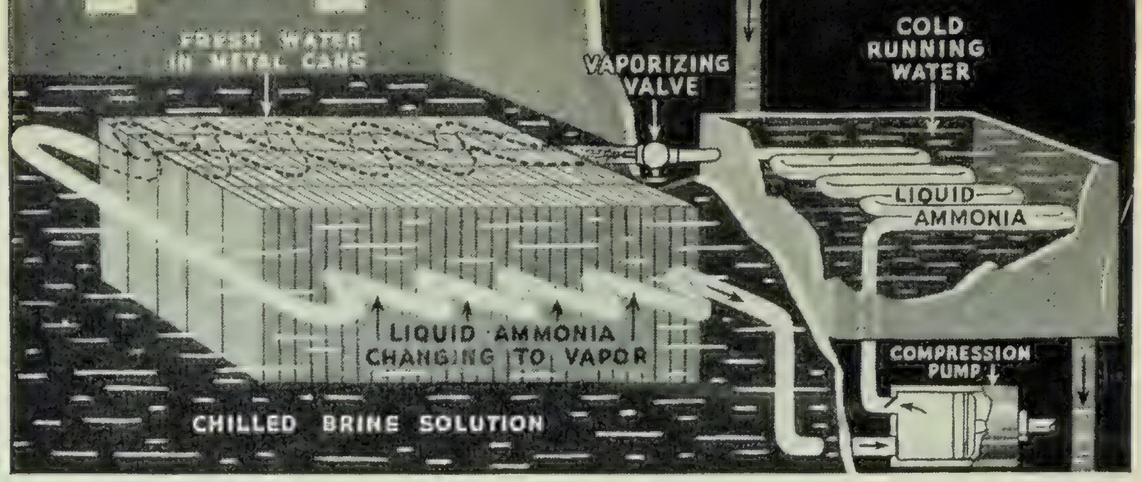


FIG. 202. Study this diagram of an ice-making plant carefully until you are sure you can explain exactly how such a plant works. What you have learned about home refrigerators should enable you to explain the ice-making machinery. Be sure that you can explain what the vaporizing valve, the cold running water, and the compression pump do.

be made very cold without freezing. Then it is circulated around tanks of water to make ice. Or it is sent through pipes to take the heat out of rooms where meat and other foods are stored.

What a mechanical refrigerating machine does, then, is to cool the inside of a refrigerator or a tank of brine by allowing a liquid to evaporate very rapidly. The vapor that is formed is then compressed and condensed so that it gives up its heat in another part of the machine. The unwanted heat is carried away by a current of air or a stream of water. Of course, good heat-insulating materials are used in the walls of refrigerators and of cold-storage rooms to help prevent the entrance of heat from the outside during warm weather.

*Self-Testing Exercises.* 1. Explain how the electric refrigerator operates by explaining what each of the following parts does: (*a*) motor, (*b*) compression pump, (*c*) condensing coils, (*d*) fan, (*e*) evaporator.

2. In what ways are an electric refrigerator and a commercial ice plant different? In what way are they alike?

3. Some boys and girls think an electric refrigerator is kept cool by the ice cubes in it. Why is this idea wrong?

*Problems to Solve.* 1. Why was a cork used in Experiment 52?

2. Trace the heat from a tray of ice cubes in an electric refrigerator or from a can of ice in an ice plant to the outside air. Remember to tell where it is conducted through metal, where absorbed by evaporating liquid, where carried by circulation, etc. Use the diagrams of the book to help you.

3. Why does a refrigerator get warm after the motor stops or, if it is an ice refrigerator, after all the ice melts?

How are buildings air-conditioned? Many theatres, some stores, and a few homes are now "air-conditioned." Complete air-conditioning includes several things. In air-conditioned buildings the air is kept at the most comfortable temperature. It is warmed in the winter and cooled in summer. The amount of water vapor in the air is kept at the correct level. It must be increased in the winter because the heating system dries the air. In the summer it may need to be decreased if the weather is humid. Dust in the air is filtered or washed out.

We usually think of air-conditioning in connection with the cooling of the air in hot weather. This requires a refrigerating machine that works like an ordinary electric refrigerator. As in a cold-storage building, the machine cools brine. The brine is then circulated through pipes over which the air is blown by large fans. This cools the air, which then passes out into the rooms of the building. A constant circulation of air is kept up from the cooling pipes into the room and back to the cooling pipes again. Usually the air is cooled below the desired temperature. This causes some of the water vapor in it to condense. Afterwards this drier air is warmed up to room temperature. It can then evaporate the right amount of perspiration from our skins to keep us comfortable.

Another method of air-conditioning buildings is that of drawing the air through a spray of water. The water cools the air, washes it, and humidifies it all at the same time. In such a system there is of course no way of taking moisture out of the air. Since in summertime it is usually desirable to reduce the humidity of the air, the refrigerating method is generally more satisfactory.

The air-conditioned cars on railroads are cooled in several ways. One plan is to put large cakes of ice in boxes underneath the cars. Air from inside the cars is blown over the ice to cool it and to condense the excess moisture. In other plans the air is cooled by a refrigerating machine on each car. This machine is operated by electricity or by steam.

Good insulation is just as important in keeping a building or a railway car cool as in keeping it warm. If heat gets in through the walls almost as fast as the refrigerating machinery takes it out,

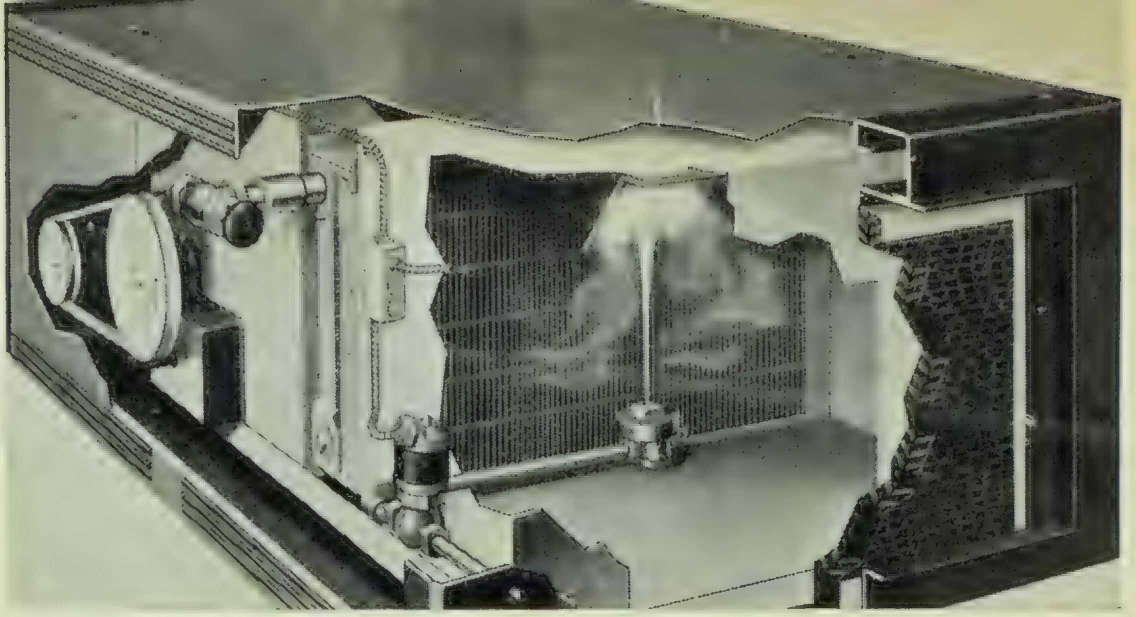

FIG. 203. This is a humidifier for use in homes. It is connected to pipes that lead to the rooms. Notice the spray of water. A fan blows the moist air up through pipes. (American Radiator photo)

air-conditioning is too expensive to be practical. Buildings and cars that are air-conditioned are tightly constructed with well-insulated walls and often with double windows. Even in hot summer weather the doors and windows are carefully kept closed.

*Self-Testing Exercises.* 1. What is meant by the complete air-conditioning of a building?

2. How is the air of air-conditioned buildings cooled?

3. How is the unwanted water vapor removed from the air in air-conditioned buildings?

*Problems to Solve.* 1. Find out how refrigerator cars and refrigerated freight trucks are cooled. Look in encyclopaedias under the topic "Refrigeration."

2. If you have an air-conditioned theatre or store in your locality, make arrangements with the manager to see the machinery and learn how it works.

## Looking Back at Unit 9

1. With the Table of Contents before you as a reminder, write down a list of what you think are the important ideas in this unit.

2. Which of these ideas do you think are the most interesting and valuable?

3. Show that you know the meanings of the following terms:

| | | | |
|---|---|---|---|
| *conduction* | *convection* | *radiant heat* | *heat transfer* |
| *convection* | *current* | *water-gauge* | *wet-and-dry-bulb* |
| *radiation* | *expansion tank* | *vacuum* | *thermometer* |
| *insulator* | *safety-valve* | *humidity* | *brine* |

## Additional Exercises

1. Make a wet-and-dry-bulb thermometer from two cheap thermometers: Select two thermometers that read about the average of all those shown in the store and that read alike. Fasten both to a board of convenient size. Remove the metal guard from the bulb of one thermometer and slip over it a piece of linen cloth that you have sewed into a tube of suitable size. Find in some science book a table giving the humidity for different readings. Then measure the humidity in your home, in your classroom, and outdoors when the air is above 32° F. Remember that the wet-bulb should be fanned before a reading is taken.

2. See how low a temperature you can obtain by evaporating ether or alcohol from a cloth wrapped around the bulb of a thermometer.

3. Tack cloth all around a cubical wooden frame. Place a thermometer so that its bulb will be inside the inclosure, but the scale will be where you can read it. Wet the cloth and see how cool the inside of your "refrigerator" will get. Many campers use this plan for keeping food cool.

4. Obtain a small porous flower-pot. Seal up the hole in the bottom with a cork and some paraffin. Hang the pot up and fill it with water. Also fill a tin can with water. With a thermometer see how much cooler the water stays in the pot than in the tin can. Why does it stay cooler in the flower-pot?

5. Why is a snow house good protection from cold weather in the arctic regions?

6. Why is a fan not needed when the condensing coils are placed on top of the refrigerator?

7. Compare a refrigerating machine with a steam-heating system. Begin by thinking where evaporation and condensation take place, where the coolest and the warmest parts are, where the systems get the energy to make them work, etc.

8. The first thin coating of ice on a pond may form overnight, but after a long time the ice may be only an inch or two thick. Give at least two reasons why the ice gets thicker so slowly.

9. Salt makes ice melt. Why does a mixture of salt and ice go far below the temperature of the ice that is put in?

10. Cold cannot be radiated because cold is only the opposite of heat. Keeping this fact in mind, explain why your hand feels cooler when it is held at one side of a large cake of ice.

11. Drop some small pieces of ice in a test-tube and then drop a small stone on top of the ice to hold the ice in the bottom of the test-tube. Heat the upper part of the test-tube until it boils. What evidence does this give you as to whether water is a good conductor or a poor conductor of heat?

12. One man reported that painting his automobile top with aluminum paint made the car ten degrees cooler on a sunny day. Do you think this could be correct? Why?

## Books to Read

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Huxley, J. S., and Andrade, E. N. da C. *Simple Science* (pages 279-317). Harper, 1935.

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Long before men had any scientific knowledge of weather, they knew that the movement of the air had much to do with weather. Wind vanes have been in use for hundreds of years, telling people which way the wind is blowing. In this unit you will learn just how important the movement of the air is in the changes that take place in the weather. You will also learn how scientists predict changes in weather. (Ewing Galloway photo)

# UNIT 10

# What Makes the Weather Change?

## Looking Ahead to Unit 10

Did you ever try to predict what the weather is going to be? Perhaps you think that you have never done so. However, if you have ever looked at the sky and said, "I think it is going to rain," or "I believe it will be hot today," you were predicting, or forecasting, the weather. It is no wonder that nearly everyone is interested in the weather. Weather makes us comfortable or uncomfortable. It determines whether or not we will go on a picnic. It determines the kinds of clothes we wear. We usually consider the weather when we make our plans for the day. It affects so many things we do that it is no wonder people frequently ask, "What's the weather today?"

Of course, weather is something that neither you nor anyone else can control. Under some conditions, it will rain; under others it will not rain. Scientists have learned how to regulate the weather in our homes, but they cannot change the weather outside. There is only one thing that scientists can do about weather. They can predict quite accurately what the weather is going to be. Scientists know what conditions cause rain, snow, or fair weather, and they usually can tell whether these conditions will be present during the next twenty-four or forty-eight hours.

Long before scientists discovered how different kinds of weather are produced, people tried to predict the weather. They watched the sky, felt the air, observed the direction of the wind, and noticed whether it was getting warmer or colder. As a result of these observations they discovered that when certain conditions are present, a certain kind of weather usually follows. They did not know why this was true; they merely knew that it was true. For example, they found that when the wind shifted into

FIG. 204. Study of weather and of the conditions which influence it is a part of the science *meteorology*, the study of the atmosphere. The headquarters of the Meteorological Service of Canada, in Toronto, is shown above. The man on the tower is making observations that will be of use in forecasting the weather for the next day.

the east, it was likely to rain. Perhaps you have heard the old weather saying, or proverb, "When the wind veers to the east, 'tis good for neither man nor beast."

Some of these old sayings may be used to predict weather quite successfully. But many of the proverbs concerning weather are nothing but superstitions. For example, many people still believe that we will have six weeks of bad weather if the ground hog sees his shadow on February 2. Others believe that the thickness of fur grown by squirrels and other animals in the fall is a sign of whether the winter will be cold or warm. Many such weather sayings are false because they are based on things that have no real connection with the weather.

Make a list of the "sayings" you have heard used to tell what the weather will be; for example, "When the sun sets red, it will be a clear day tomorrow." Keep your list, and, as your study progresses and you learn more about weather, write the word "Superstition" after those signs and sayings that cannot be explained by the facts of science. Write "Scientific" after those that can be explained by the facts. How are we to tell which sayings are correct and which sayings are incorrect? How can we become fairly accurate in predicting what the weather is likely to be? The best way to learn how to predict the weather for yourself is to understand what causes changes in weather.

There is a great deal that scientists do not yet know about weather and climate, and a great deal of what is known you will not have time to study about in this unit. But you will be able to think about the most important of these problems and to learn many things about them. By outside reading you may also learn other interesting things not told in this book. Keep in mind as you study this unit that what you are studying is not the book, but the weather. Weather is all about you and is probably more easily observed than any other part of science you will study.

If you wish really to learn, you will be alert to see for yourself the things you read about and to discover by your own observations and experiments facts which are not in the book. You can begin doing so by making a chart like the one below. Record your observations, using the symbols given on page 330 for the column headed *Condition of Sky*. You can obtain your barometer readings from the newspaper. What do these observations show about the conditions of the weather when the barometer reading is highest? When it is lowest?

| DATE | TIME | ATMOSPHERIC PRESSURE | TEMPERATURE | DIRECTION OF WIND | CONDITION OF SKY | KINDS OF PRECIPITATION |
|---|---|---|---|---|---|---|
| March 1 | 9:00 A.M.<br>4:00 P.M. | | | | | |

## 1. What causes the different kinds of weather?

HOW DO WE DESCRIBE WEATHER? Usually one of the first things we do in the morning is to peek outside to see what the weather is. We look at the sky to see whether the sun is shining, at a thermometer to see how warm or cold it is, and at the trees to see how hard the wind is blowing. If we have a morning paper, we read the weather forecast. Or we may turn on the radio and hear the weather forecast. From this information we get an idea of what the weather will be for the day.

The words that you use to describe weather really tell what weather is. You look at the sky, and you say that it is fair, clear, cloudy, rainy, foggy, or snowy. These words are used to tell what is happening to the moisture content of the air. If it is fair, or clear, moisture is not coming out of the air. If it is cloudy, rainy,

Fig. 205. Because the weather reports in the newspapers and over the radio predicted rain or snow for the day, hundreds of people protected themselves by wearing heavy coats and carrying umbrellas.

or foggy, the water vapor in the air is condensing; that is, it is changing to liquid water. Sometimes you say that the air is "muggy," humid, or dry. Here you are describing how the air feels to us. If the perspiration does not evaporate quickly from your body, you say that the air is humid. By this you mean that the air contains a great deal of water vapor. If your skin feels parched and perspiration evaporates quickly, you say that it is "dry" weather. Usually when you describe weather, you use some word or words to tell about the moisture in the air.

No description of weather would be complete without some mention of the temperature of the air. You say that it is cold, cool, warm, or hot. Often you say that it is cooler or warmer. What you mean is that the temperature of the air is higher or lower than it was the day before.

Another important part of weather is the way the air is moving. You describe the movement of the air by saying that the weather is calm, still, windy, or breezy. You tell the direction of the wind by mentioning the direction from which it is blowing. A north wind, for example, is a wind blowing from the north. This movement of air is a very important part of weather.

From this description you can see that the weather at any time depends upon the way the air is moving, the temperature of the air, and the condition of the moisture in the air. That is, the weather at the place where you are is simply the condition of the air that surrounds you. Now let us find out what causes the different kinds of weather.

HOW IS THE AIR WARMED? As you already know, the heat that warms the air-covering of the earth comes from the sun (page 284). The sun warms the earth by sending waves of radiant energy through the space between the sun and the earth. Only a small part of the radiant energy from the sun changes to heat when it passes through a colorless material like air. But when it strikes a material which holds it or absorbs it, as soil or rock, much of the radiant energy is changed to heat. When the materials on the earth's surface become warm, the air is warmed by coming in contact with them. The rock and soil, warmed by the radiant heat they have absorbed from the sun, pass their heat by conduction to the air that touches them.

The extent to which the air will be warmed depends upon the temperature of the surfaces with which it comes in contact. Water, for example, warms up much more slowly than soil; therefore the air over a body of water is likely to be cooler than the air over land. For the same reason the temperature of the air over different kinds of soil, over forests, over mountains, and over valleys will vary. This happens because these surfaces differ in the amount of radiant energy they absorb and change to heat and in the amount of heat that they pass on to the air. You will see later how these differences in the temperature of the air over certain kinds of places affect the weather.

*Self-Testing Exercises.* 1. When you describe the weather, what are you really talking about?

2. Across a sheet of paper write the three words *Moisture*, *Temperature*, and *Movement*. Under each word write in a column the words used to describe that part of the weather.

3. Why does a thermometer in the sun register a higher temperature than a thermometer in the shade?

4. Why does the temperature of the air depend upon the surface of the earth with which it comes in contact?

WHY DOES THE WIND BLOW? Wind, as you already know, is a current of moving air. Winds vary greatly in speed. Sometimes they move so slowly that they can merely stir the leaves on a tree. At other times they may blow hard enough to uproot trees and overturn buildings. Sometimes they blow from one

direction and sometimes from another. Your problem is to discover why air moves and why it changes in speed and direction. You already know three facts about air which will help you find an answer. From Experiment 1, page 34, you know that air has weight. You also know that it expands when it is heated (Experiment 11, page 75) and that a cubic foot of cold air weighs more than a cubic foot of warm air. You know, too, that air will not move unless some force makes it move.

If air has weight, it must press down on the surface of the earth. You press down on the chair in which you are sitting. If you weigh 100 pounds, you press down with a force of 100 pounds. This is the pull that gravity has on you. Air, as you know, extends upward for a distance of 500 miles or more. It presses down on the earth in the same way that you press down on a chair. If we had a way to measure the weight of the air above us, we would find out just how much this downward pressure is. While we have no method of weighing the air above us by using a pair of scales, we do have a way of finding out what its weight is. We do this with an instrument called a *barometer*. You can easily make a barometer.

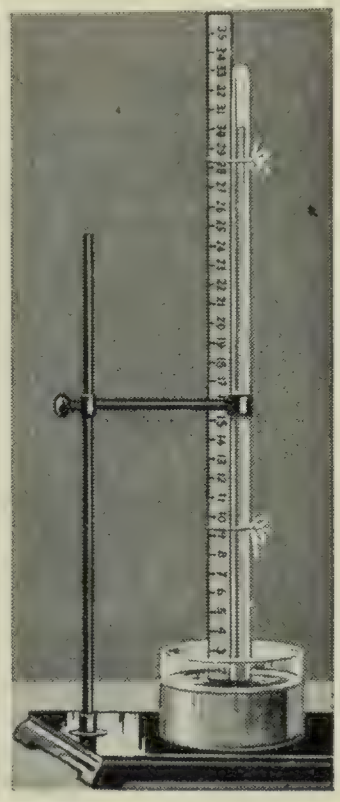


FIG. 206

*Experiment* 53. HOW IS A BAROMETER MADE AND USED IN MEASURING AIR-PRESSURE? Heat one end of a glass tube about three feet long in a flame until it melts and closes. When it is cool, fill it with mercury. Place your finger over the open end and invert it in a dish of mercury (Figure 206). Does the mercury completely fill the tube after your finger is removed? What is left between the mercury and the top of the tube?

Now measure the height of the mercury in the tube above the level of the mercury that is in the dish. Allow your barometer to stand, and measure the height of the mercury column from day to day. Explain why this height changes. Record your observations in a table like the one on the next page. Is there any relation between the height of the mercury and the kind of weather?

Now let us see what the experiment shows. When you take your finger off the tube under the surface of the mercury, a little of the mercury runs out, but about thirty inches of the mercury

AIR-PRESSURE AND SKY CONDITIONS

| DATE | MERCURY HEIGHT IN INCHES | FAIR, CLOUDY, OR RAINY DAY |
|---|---|---|
| Jan. 10 | 28.5 | Rainy |

stays in the tube. The weight of the air above the mercury in the dish pushes down on the mercury. The air does not press on the mercury in the glass tube because the top of the tube is closed. The weight of the air on the outside of the tube balances the weight of the mercury on the inside. In this way the mercury acts like a pair of scales. The mercury stays in the tube because it is held up by the pressure of the air on the outside. Your readings showed that the height of the mercury changed from day to day. As the air-pressure becomes less, the mercury falls until it just balances the air. As the air-pressure increases, the mercury is forced up until it again balances the air.

Now if we know the weight of mercury that can be held up by the air, we can find the weight of the air. Suppose that the end of the barometer tube has an area of one square inch and the height of the mercury in the tube is 30 inches. This would mean that there are thirty cubic inches of mercury in the tube. One cubic inch of mercury weighs .49 pound. Thirty cubic inches of mercury piled on top of one another would press down with a force of 30 x .49 pounds, or 14.7 pounds. Thus when the mercury stands thirty inches high in the tube, the air-pressure is almost fifteen pounds on every square inch of surface. What this really means is that the column of air above each square inch of surface on the earth weighs about fifteen pounds. The scientist says that the *air exerts a pressure* of about fifteen pounds per square inch at the surface of the earth. In scientific experiments and in navigation the air-pressure is often given in number of inches of mercury, thus: *The barometer reads 30 inches.*

As the inch is a standard of length, meteorologists prefer to measure the pressure of the atmosphere by the millibar, a

standard of pressure. They say that one cubic centimetre of water, weighing one gram, exerts a pressure of one millibar on the surface upon which it rests. About 1016 cubic centimetres, piled one on top of the other, exert the same pressure as that of a column of 30 inches of mercury. Thus a pressure of 1016 millibars corresponds to a pressure of 30 inches of mercury. The millibar is now used on nearly all weather maps.

Mercury barometers are quite inconvenient to carry around; so inventors have devised a more convenient instrument called the *aneroid* (without liquid) barometer. The aneroid barometer is shaped much like an alarm clock (Figure 207). Inside the case is a cookie-shaped metal box with circular ridges on it. This metal box has had the air pumped out and has been sealed air-tight. A strong spring keeps it from being crushed by the atmosphere. As the air-pressure changes, the sides of the vacuum-box move in or out. This motion of the sides of the box is carried to a pointer that moves back and forth around the face of the instrument.


FIG. 207. An aneroid barometer (Taylor Instrument Co. photo)

Aneroid barometers are used by surveyors and mountain climbers to measure changes in height above sea-level. The *altimeter*, by which an aviator tells how high above sea-level he is flying, is an aneroid barometer especially made for that purpose.

As yet, you have not learned the answer to the question, "What makes air move?" In Problem 1 you learned that the temperature of the air is different at different places at different times. This, of course, means that the air-pressure will be different at different places. Where it is cold, the pressure will be greater than where it is hot. Let us suppose that the pressure in one place is fifteen pounds per square inch, while in another place it is fifteen and one-half pounds per square inch. The air at the place of high pressure (fifteen and one-half pounds) will flow along the surface of the earth to the place of lower pressure (fifteen pounds) and push this lighter air upward.


FIG 208. During the day, when the air over the land is warmer than the air over the water, a breeze blows toward the land. At night, when the air over the land is cooler than the air over the water, a breeze blows toward the water. Why does the land take in and give off heat more rapidly than the water? (See page 285.)

A wind thus results from a difference in the air-pressure at two places. The force causing the wind, of course, is the pull of gravity. You can see further that if the difference in pressure is very little, only a gentle breeze will blow. If the difference in pressure is very great, a strong or fast-moving wind will result.

Now let us see how *local* winds, that is, winds that affect only small areas, are produced. For example, suppose that you live on the shore of a large body of water. The sun warms both the land and the water, but the water does not get warm as quickly as the land. Therefore the air over the land is warmer than the air over the water. If the difference in the weight of the air becomes great enough, the heavier, cooler air over the water will flow toward the land. Thus we have a sea breeze or a lake breeze along the shore.

If you live in a valley, you have probably noticed the cool wind that flows down the side of the mountain after a hot day. Late in the afternoon and at night the valley sides cool off by radiation to outer space. The air just above the surface then becomes cool by contact with the cold ground. As the air at the same height in the centre of the valley is not near a ground surface, it cools very little, and the cooler, denser air near the valley sides begins to sink. This cool, sinking air is the breeze that you may have noticed.

There are, of course, many other conditions that produce local winds. The air over forests is cooler than the air over grasslands. The air over grasslands is cooler than air over plowed fields. Differences in the temperature of such places close together thus bring about light breezes. These winds, however, affect only small areas. They bring about changes in temperature and weather conditions for a distance of only a few miles. A shift in the wind in Kingston so that the lake breeze flows toward the land may make the temperature ten degrees cooler. Ten miles inland, however, the temperature may not change.

The winds about which you have just learned are winds that affect only small areas. They are caused by differences in air-pressure resulting from the unequal heating of places close together. They do not affect the weather to any great degree. The winds that produce important changes in the weather over wide areas are the result of great whirlpools of air which move across our country. You will learn about these in Problem 2.

*Self-Testing Exercises.* 1. Why does air exert pressure?

2. How is the pressure of the air measured?
3. Why does the height of the barometer change from day to day?
4. How are local winds caused?
5. How does an aneroid barometer work?
6. Why are the tops of mountains cooler than the valleys?

*Problems to Solve.* 1. When a barometer is carried up the side of a mountain, will the mercury rise or fall? Why?

2. The face of an ordinary aneroid barometer (Figure 207) has numbers from 26 to 31 "inches." What do those numbers mean?

3. How many tons of air are there over a city lot 40 feet by 125 feet when the barometer stands at 30 inches?

4. How is the action of the mercury in a mercury barometer different from that in a mercury thermometer?

5. What is the total force of the atmospheric pressure on the outside of a man's body if the area of the surface of his body is 18 square feet? Why can we not feel this pressure?

WHY DOES THE MOISTURE IN THE AIR CHANGE? First, let us review a few facts that you already know. Water poured into an open pan will disappear if it is left for awhile. Wet clothing soon dries. After a rain the streets and ground become

dry. You know that in each of these cases the water evaporated; that is, it changed to a gas, or water vapor, and its molecules mixed with the other kinds of molecules that make up the air. You might think that water will always evaporate into the air, but let us see what an experiment shows.

*Experiment 54.* IS WATER ALWAYS EVAPORATING INTO THE AIR? Obtain two wide-mouthed bottles or beakers. Fill each bottle half full of water. Be sure that you pour the same amount of water in each. Paste a paper on each bottle to show the height of the water in the bottle. Cork one bottle and leave the other open. Allow them to stand for several days. Each day measure the amount of water that has evaporated by measuring down from the edge of the paper.

Does water evaporate from both bottles? Does water keep evaporating in the bottle that is corked, or does it stop evaporating? Does water continue to evaporate from the open bottle, or does it stop evaporating? How do you explain the difference in results?

Before we try to explain what happened in this experiment, let us see how the conditions in the two bottles were different. In the open bottle the molecules of water that escaped into the air could move out of the bottle into the outside air. In the closed bottle the molecules of water that escaped into the air above the water could not leave the bottle. As more molecules bounced out of the water, the air became more crowded with water vapor. Finally a point was reached when the water stopped evaporating because the air could hold no more water molecules.

Why did the water stop evaporating? The reason is that air can hold only a certain amount of water vapor at any temperature. When it contains all of the water vapor it can hold, we say that it is *saturated*. When the air is saturated, no more water vapor is able to evaporate into it.

If you pour cold water over the corked bottle used in Experiment 54, drops of moisture will collect on the inside of the bottle. Some of the water vapor in the air in the bottle changes back to liquid water, or, as we say, it condenses. How do you explain this? First of all, you know that the air was saturated. When you poured cold water on the bottle, the air in the bottle was cooled. Then some of the water vapor condensed. Why did this happen?

The only explanation we can think of is that cold air cannot hold as much water vapor as hot air. And this is true. The hotter the air is, the more water vapor it can hold. When air becomes saturated at a temperature of 90° F., it contains five times as much water vapor as saturated air at 40° F.

If warm air can hold more water vapor than cold air, we should be able to make water vapor condense from air if the air is cooled enough. You have already done an experiment which showed that this does happen. In Experiment 12, page 78, you made water vapor condense from the air around a cup by cooling the cup with ice. If the air contains a great deal of water vapor, a slight amount of cooling will make condensation take place. The drier the air, the more it must be cooled to make the water vapor condense from it.

FIG. 209. The action of molecules of water in a closed bottle and in an open bottle

Let us summarize what you have learned about the moisture in the air. Water is evaporating from the surface of bodies of water, from fields, and from other moist surfaces so long as the air is not saturated. The warmer the air is, the more water vapor it can hold, and the faster water evaporates into it. But when air is cooled, its capacity to hold water and to take up water by evaporation is decreased. If air is cooled enough, it finally reaches its saturation point, or *dew point*. Then no more water will evaporate into it because it can hold no more water. If it is cooled below its dew point, some of the water vapor will condense to liquid water.

Now, how does the direction of the wind affect the amount of moisture in the air? A wind that blows from the south toward the north is blowing from a warm place to a cooler place. What is happening to its capacity to hold water vapor? Is it decreasing or increasing? Since the air is getting cooler, you know that its capacity to hold water vapor is decreasing. If it is cooled enough,

Fig. 210. Where do you think dew (shown at the left) and frost (right) come from? (U. S. Weather Bureau photo)

condensation takes place, and we have rain, snow, or fog. Sometimes, as you have learned, the air moves upward. As it moves upward, it is cooled and its water vapor is condensed. Rising currents of air are the main cause of condensation of water vapor.

What happens when winds blow from the north? As the air moves south, it is warmed; therefore it can hold more water vapor. The clouds disappear, and the weather turns fair. A similar thing happens when air moves downward. As air is warmed when it descends, it can take up more water vapor, and the droplets that form the clouds evaporate.

From what you have learned, you now can see that rain, snow, or other forms of *precipitation* are likely to fall if the wind blows in such a direction that the air is cooled. The more humid the air is, the greater the possibility of rain, because humid air needs to be cooled only a little to become saturated. Fair weather will come if the wind blows in such a direction that the air is warmed. In Problem 2 you will see how these conditions are brought about.

How are different kinds of moisture-fall produced? Sometimes when you go out-of-doors early in the morning, you find that the grass is wet with dew or that the ground is covered with a white blanket of frost. At other times the ground is quite dry; there is neither dew nor frost. You have also had the experience of seeing moisture come out of the sky in three different forms—rain, snow, and hail.

Before you read the explanations of how dew, frost, rain, hail, and snow are formed, try to remember what the weather was like when you saw these different forms of moisture coming from the

FIG. 211. These clouds are called *cirrus* clouds and are the highest ones in the sky. They form at an average height of six miles, but sometimes they are as far as nine miles above the earth. They are made of tiny crystals of ice and always look white. (F. Ellerman photo)

air. There is a certain set of conditions necessary to produce each kind of moisture. What are these conditions?

During the day as the earth is warmed, water evaporates into the air from the moist earth, from plants, and from lakes, rivers, and other bodies of water. When the sun goes down, the earth cools off. The heat is radiated through the air and out into space. The air close to the earth and to objects on the earth is sometimes cooled below its saturation point, or dew point. Then moisture forms upon the ground, buildings, and other objects.

Moisture that forms in this manner is called *dew*. Dew is more likely to form on still nights than upon windy nights. If the wind is blowing, the cold air near the ground is mixed with the warmer air; therefore the air near the ground is not cooled below its saturation point. If the temperature at which the saturation point is reached is below freezing, moisture will come out of the air in the form of feathery crystals of ice that we call *frost* (Figure 210). Frost is not frozen dew. The water vapor in the air changes directly to a solid (frost) as it separates from the air.

If you have ever climbed a high mountain or have ridden in an aeroplane, you may have gone through a cloud. If you have not done this, you surely have walked or driven through a *fog*. Actually, a fog is just a cloud that is close to the ground. When the temperature of a rather thick layer of air near the earth falls below the saturation point, a fog is formed. Water vapor condensing on particles in the air forms tiny drops of moisture.

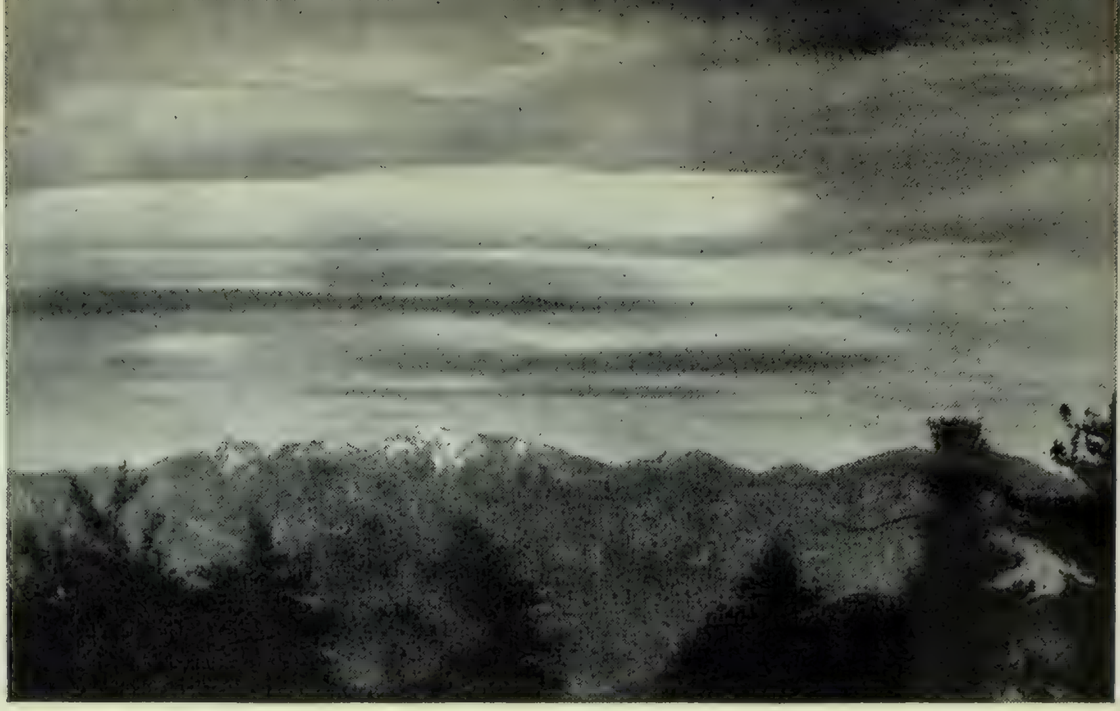


FIG. 212. The clouds in this sky are typical *stratus* clouds and are one of the commonest kinds of clouds. They are always smooth gray, and generally hide the moon or sun. They usually form at a height of about 2100 feet, although they may be as low as 400 feet. Such clouds may appear before long, steady rains. (F. Ellerman photo)

These drops float in the air. There are so many of these tiny drops floating in the air that the air looks white. Sometimes they get large enough so that we can see the separate drops.

Clouds are formed in the same way as fog except that they are in the air above us. The air may be cooled in two ways to cause the water vapor to change into the droplets that make clouds. Warm air that contains much moisture may be blown into a cool region. Here it will be cooled below its saturation point. Or warm air may rise and become cooler; then the water vapor in it may condense. There are three types of clouds that are very easy to recognize. Look at Figures 211, 212, and 213 and read the descriptions of these three types of clouds. These pictures will help you recognize the most common kinds of clouds when you see them in the sky.

Clouds, as you have seen, consist of tiny droplets of water floating in the air. Sometimes rain falls from the clouds we see, and sometimes it does not. Before rain will fall from a cloud, the droplets of water must get so large that they can no longer float in the air. Let us see how this takes place. If a cloud once formed by the cooling of the air is cooled still further, the air can hold less water vapor; therefore more condensation will take place. Some of the water vapor will condense on the drops of water already present in the cloud. This will make these drops larger. As the air moves, drops of water are brought close together.

FIG. 213. Sometimes on a hot summer day you see "thunder-heads," or *cumulus* clouds, towering into the sky. These clouds are formed when warm, moist air ascends. When the warm air reaches the point where it becomes cooled to the saturation point, the water vapor in it begins to condense, and we see these clouds with the many interesting shapes. The tops of cumulus clouds average about 6000 feet above the earth while their bases, which are usually flat, may be within a few hundred feet of the earth. Such clouds often precede a local storm, especially a thunder-storm. (F. Ellerman photo)

When they touch, they unite and form larger drops of water. In these two ways the droplets that make up the cloud finally get so large that they fall to the ground as rain.

Sometimes raindrops fall into a layer of air near the surface of the earth that is below freezing. When this happens, the drops freeze and fall to the ground as *sleet*. At other times, especially during summer thunder-storms, in the cold air high above the earth water vapor may condense as ice crystals which fall into warmer air and become coated with water. Then they are lifted by strong upward currents into the cold upper air, where they freeze. This process continues until the balls of ice that are formed are too heavy to be held up by air currents. These pieces of ice then fall to the earth as *hail*. Sometimes hailstones may be found which, cut in two, show by layers of ice their history of ups and downs (Figure 214).

FIG. 214

Snow, like frost, is formed when the saturation point of air is below freezing. The water vapor in the air forms tiny particles of ice as it separates from the air. These particles of ice grow and form crystals of snow. Figure 215

shows a photograph of some of the lovely crystals that are formed. The very large flakes that fall in some snowstorms are really made of many crystals that happened to join together as they fell. Like rain, the snow falls when the flakes are so large that they are no longer able to float in the air.

You can now see that while the conditions necessary to produce dew, frost, rain, snow, and hail differ in some ways, in one way they are the same. The air must be cooled below the saturation point before water vapor will condense into liquid water or form solid crystals.

*Self-Testing Exercises.* How long does water continue to evaporate into the air?

2. What happens to saturated air when it is cooled?

3. Which can hold the more water vapor, cold air or warm air? State a proof for your answer.

4. What kind of air will form dew when it is cooled only a little? What kind of air must be cooled a great deal to cause condensation?

5. What change or changes in the air are likely to bring rain? Fair weather?

6. Explain how each of the following is formed: dew, frost, fog, cloud, sleet, hail, and rain.

*Problems to Solve.* 1. Is it correct to say that dew and frost fall?

2. Get a good book on weather and find what some of the important types of clouds are. Then watch the skies to see if you can actually see any of them. Which kinds of clouds indicate the coming of rain or snow? Which kinds indicate fair weather?

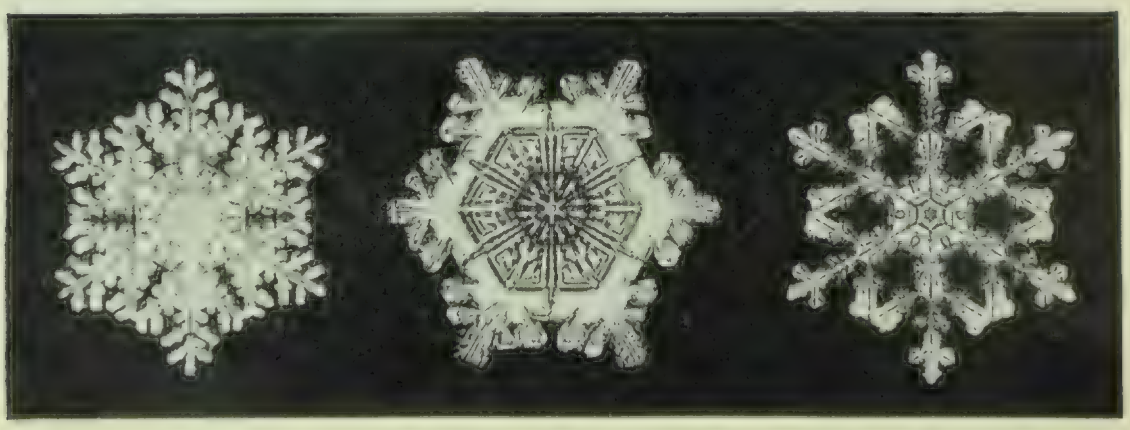


FIG. 215. No two snow-flakes ever look exactly alike; although they all have six points. (W. A. Bentley photo)


FIG. 216. Diagram for Problem 3

3. Wind from the Pacific Ocean blows eastward over the Coast Range (Figure 216). There is much rainfall (in the form of both snow and rain) in the mountains and comparatively little rainfall on the eastern side of the mountains. Explain these conditions.
4. Why do you see your breath on cold and not on warm days?
5. Frost does not usually form on a cloudy night. Explain.
6. Why does heating make moist air dry?
7. Icebergs are often surrounded by fog. Explain.
8. When the sun comes out, fogs disappear. Explain.

## 2. Why does the weather change from day to day?

WHAT DO WEATHER MAPS SHOW? Let us examine a map issued by the Meteorological Service to see what we can discover about the ways in which weather changes. First, what do the different marks tell about the weather? Look for circles marked "HIGH" and "LOW." Around these words you will see a series of black lines. Each line has a number, such as 1014, 1020. This number shows the pressure in millibars (page 318) along that line. These lines are called *isobars*. Before the map is made, weather observers all over the continent report by telegraph the air-pressure and other weather conditions at their stations. Then the weather forecaster draws a line connecting all the places on the map that have the same pressure. Each line, or isobar, thus shows the places that have equal pressure.

If you examine the isobars around a "low," you will see that the pressure is the least in the centre. For example, the isobar marking the centre of the low may be 984. The next one from

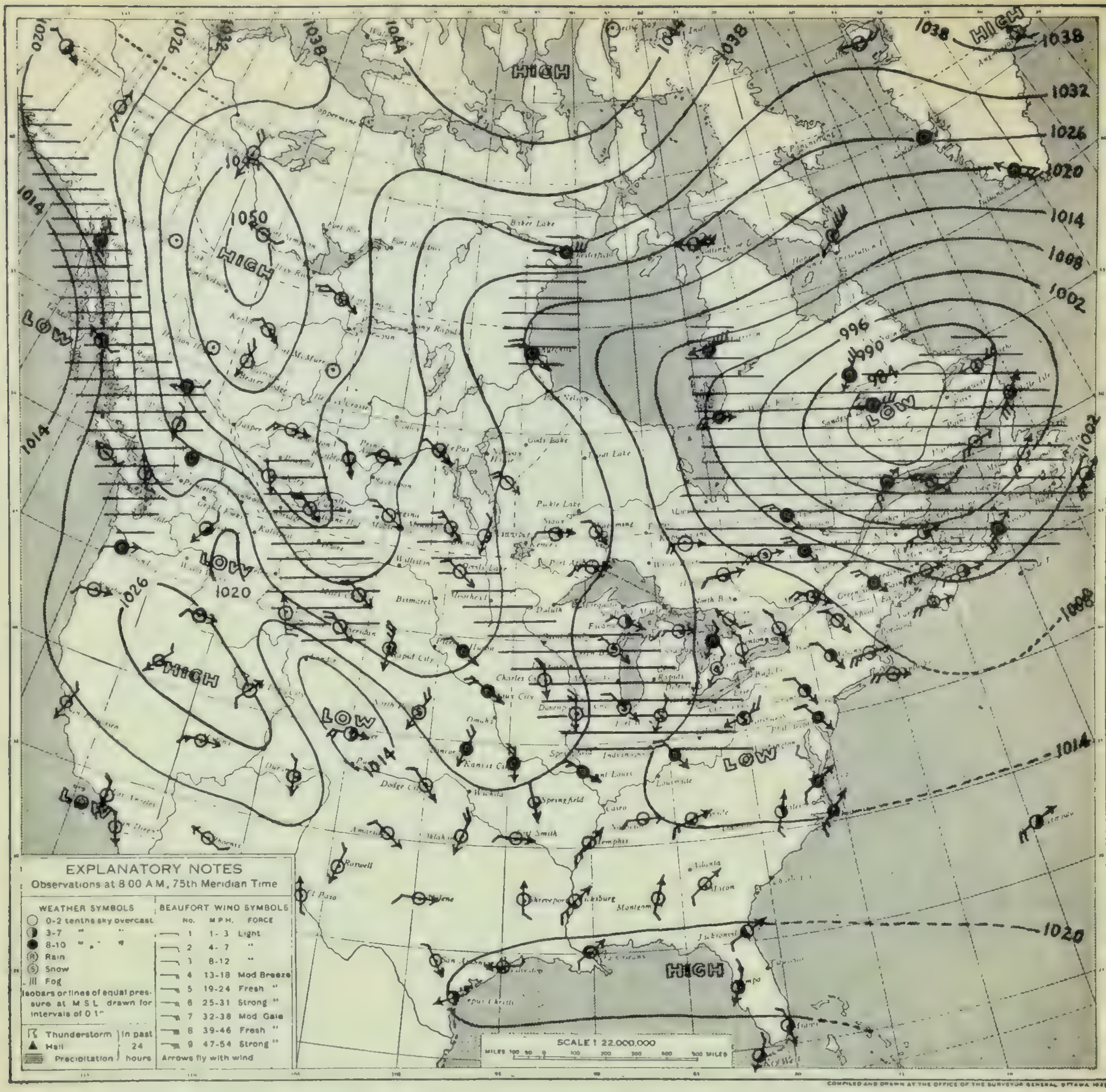



FIG. 217. A weather map such as those made daily by the Meteorological Service of Canada from observations taken every morning at 8.00 A.M. across the continent (Courtesy Meteorological Service of Canada)

the centre may be 990, etc. Thus a "low" is a place of lowest air-pressure. A "high" is exactly opposite from a "low." The isobars show that the place of highest air-pressure is in the centre, and the pressure decreases as one travels outward from the high.

Each of the stations at which observations are made is indicated by a circle. The condition of the sky is shown by the following symbols: clear, ○; partly cloudy, ◐; cloudy, ●; rain, ®; snow, Ⓢ. Arrows on the circles show the directions of the wind. Arrows fly with the wind; that is, if an arrow points north, the wind is blowing from the south. If an arrow points east, the wind is blowing from the west.

Now let us see if we can find any difference between the


FIG. 218. This map shows the movement and position on successive days of cold air masses from the north-west Arctic regions.

weather in a "high" and in a "low." In Figure 217 look at the circles showing the condition of the sky at different places. Is the weather fair or stormy in places of low pressure? In places of high pressure? Really to answer this question scientifically you would need a large number of maps, because the weather on one day may not be typical of what usually happens. Examination of many maps would show that the weather in regions of low pressure is usually cloudy, with rain or snow, while the weather in a "high" area is usually fair, that is, clear and sunny.

Look at Figure 217 and notice the positions of the "highs" and "lows." If you could examine maps for the days succeeding this one, you would see that the regions of high pressure and low pressure have moved across the country. Now you can see why weather conditions will change. Regions of low pressure bring clouds, with rain or snow. If they move across the country, the rains will also move across the country. Regions of high pressure bring fair weather, and, as they move across the country, places in their paths will usually have an improvement in weather. Changes in weather conditions are thus the result of the movement of "highs" and "lows" across the country.

An important detail on weather maps, not shown in Figure 217, is temperature. Reports of temperature from the meteorological stations over the continent usually show large areas in which the temperature is nearly the same. At the border of one of these areas, however, the temperature may change rapidly.

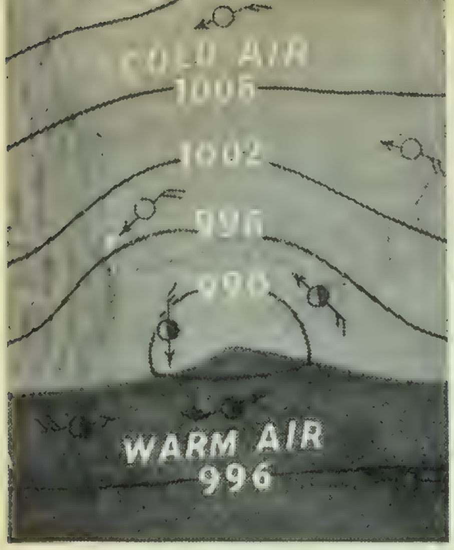



FIG. 219a

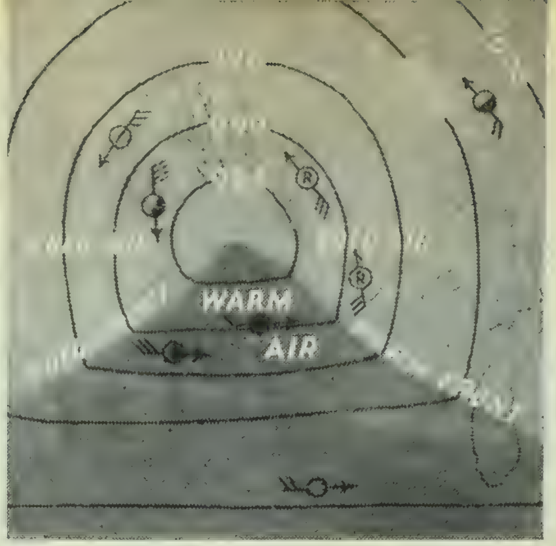



FIG. 219b

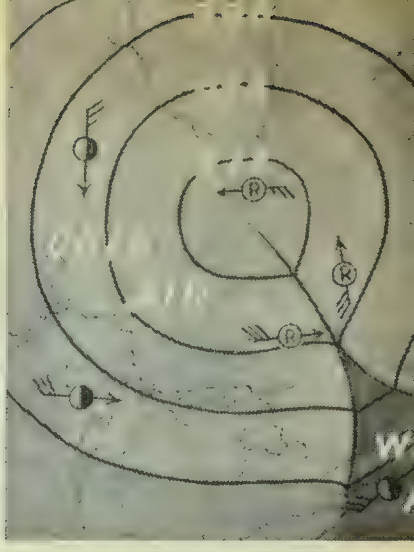


FIG. 219c

For example, over an area for 200 miles west of Montreal, the temperature may be about 30° F. Near Montreal the temperature may rise rapidly, and east of the city, over another large area, the temperature may be about 45° F. Bodies of air which have nearly constant temperature for hundreds of miles are known as *air masses*. The moisture content of air masses is usually nearly constant also. The region between air masses, where temperature and moisture conditions show considerable difference in a small distance, is known as the *front*. In Figure 218 notice the movement of the cold wave across the continent. You can see how the front, with the cold air behind it, brought cold weather first to the prairie provinces and later to eastern Canada and the United States.

WHY IS THE WEATHER UNSETTLED DURING PERIODS OF LOW PRESSURE? "Lows" often develop at the front separating a warm air mass from the south and a cold air mass from the north. The air starts to move in an anti-clockwise manner (which is the general direction of the wind in areas of low pressure), and at the same time a sharp bend develops in the front, as shown in Figure 219. There are then two main parts to the "low," a warm part or *warm sector,* as it is called, made up of warm, moist air from the south and a *cold sector* of cold dry air from the north. The part of the front to the west of the centre, where cold air is pushing in under warm air, is known as the *cold front,* and the part to the east, where warm air is flowing up over cold air, is called the *warm front.*

The cross section shown in Figure 220, shows the cold air at the west pushing in like a wedge under the warm air. On the east, the warm air flows up over the cold air ahead. The warm air at the right cools as it rises, and finally becomes saturated

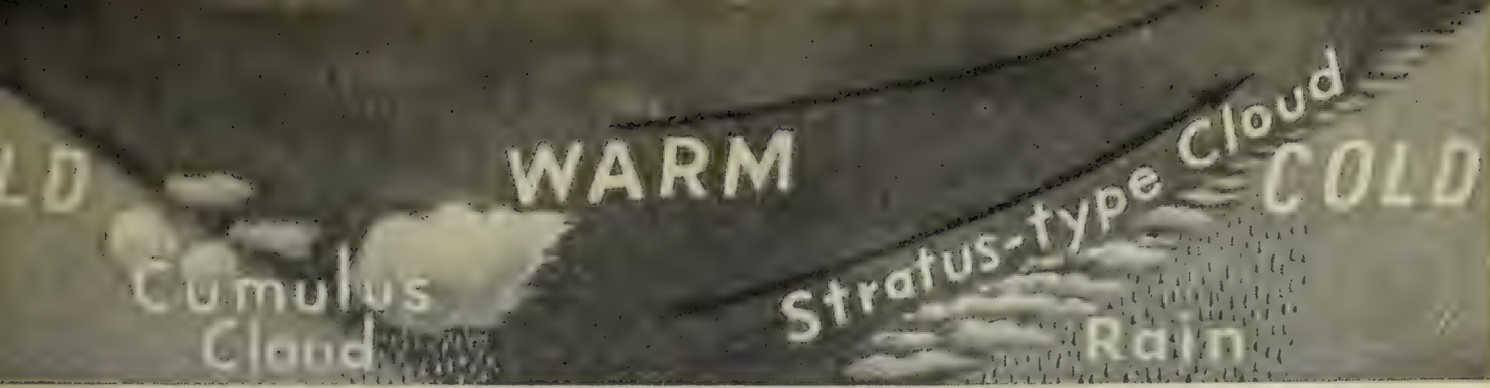



FIG. 220. How cold air pushes in under warm air

with condensed water vapor, resulting in stratus clouds and steady rainfall ahead of the warm front.

As a warm front of this type approaches, clouds hide the sun, rain begins to fall, and the pressure decreases. As the warm front passes, and the warm sector moves in, the rain often stops, and the wind shifts from south or southwest to west. During the time that you are in the air of the warm sector, the pressure does not change very much, the air is warm and muggy, with perhaps light rain or drizzle. Then comes the cold front with perhaps showers and gusty winds that shift from west to northwest. The pressure starts to rise after the cold front has gone by, cumulus clouds are often seen, and the air is colder and drier. As the "low" travels across the country, the fronts rotate about the centre of the low pressure in an anti-clockwise manner, similar to the spokes in a wheel. The cold front, however, moves more rapidly than the warm front, thus it catches up to the warm front. When this happens the "low" becomes weaker, and usually disappears after a day or two.

You can see from the diagrams (Figure 219), that fronts will pass only if the centre of the "low" passes to the north of you. These three diagrams show what you would be likely to see if you could watch a "low" develop. In examining the diagrams, imagine that you are looking straight down upon the surface of the earth. Notice in Figure 219a that between a warm air mass from the south and a cold air mass from the north a bulge begins to move in an anti-clockwise direction. In Figure 219b the "low" has moved eastward, and the bulge has increased into a definite warm sector. To get a picture of the shape of the whole mass of warm air in the middle diagram, think of a triangular saucer, the warm air flowing up at the right over the wedge of cold air that lies under the edge of the saucer, and at the left, a wedge of cold air pushing in under the warm air. (See Figure 220.) Over the region between Lake of the Woods and

Lake Superior, rain will probably be falling; then as the "low" moves eastward people in the area will feel the soft breezes of the warm front. When the warm sector has passed, the cold front brings cooler weather and possibly chilly showers. In Figure 219c the cold front is catching up to the warm front; from this point on, the pressure will likely begin to rise, and the "low" may disappear. The three diagrams might be taken to represent the character and position of a certain "low" on three successive days. As the low develops, notice the changes in direction of the lines that indicate isobars. Pressures are shown in millibars.

High pressure areas, or "highs" may be thought of as just the opposite of "lows." The air moves around a "high" in the opposite direction to that around a "low," that is, in a clockwise direction. As the air is heavier in a "high" it descends, and as it falls it becomes warm. Being warm it can hold more water vapor, condensation does not occur, and skies are therefore usually clear. Fronts are never found in "highs."

"Highs" and "lows" move from west to east, generally speaking. They may move some distance to the north or south, or they may have very little motion for a time, but the general motion is eastward. A series of weather maps for a week or so would show this fact clearly. Predicting weather, as you will see in the next problem, is largely a matter of finding out how the "highs" and "lows" will move during the next forty-eight hours.

*Self-Testing Exercises.* 1. Suppose that you are teaching someone how to read a weather map. What would you tell him?

2. What kind of weather usually occurs in a "low"? Explain why.

3. What kind of weather usually occurs in a "high"? Explain.

4. Suppose that a region of low pressure is west of you. What will be the direction of the wind at the place where you are?

HOW DO LOCAL STORMS BEHAVE? Regions of low pressure, as you see from the weather map, cover large areas. They may be hundreds of miles in diameter. There are also storms that are local in character. They affect only a very small area.

Think of a thunder-storm that you have seen. How quickly it forms! How the lightning flashes, and how soon the storm is over! The weather was probably fair and warm for several days

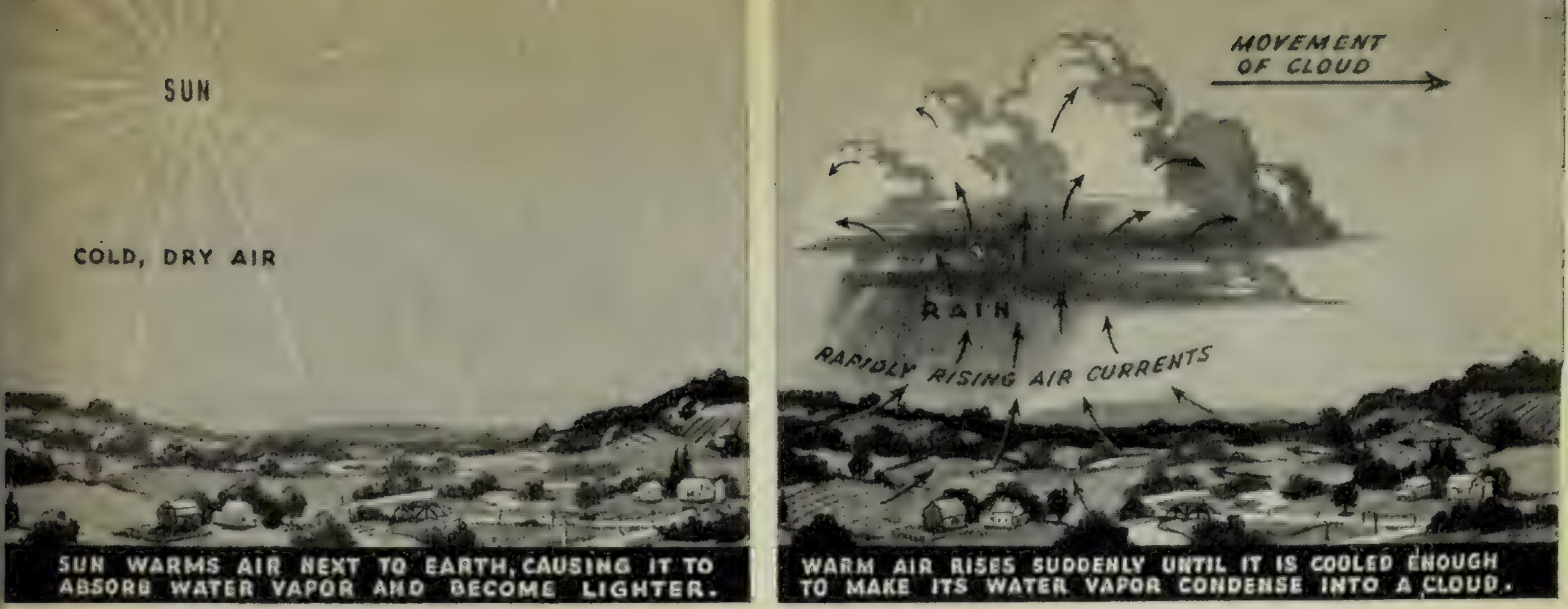



FIG. 221. How a local thunder-storm is caused

before, and a few thin cirrus clouds were to be seen. What makes such storms happen? On a warm summer day the land absorbs much heat. But open spaces become warmer than surrounding grassy and wooded places. The air over these places becomes heated and is forced upward until it is cooled enough to make its moisture condense into a cloud. Each towering thunder-head is the top of a huge current of rising, moist air.

These cumulus clouds, as you know, have large, rounded tops. The bottoms are flat because rising moisture begins to condense at about the same height in all parts of the current (Figure 221). The clouds become larger, darker, and more towering. Flashes of lightning and rumblings occur. It is thought that drops of water in the rising currents of air produce a charge of electricity in the cloud. When the charge becomes great enough, a large spark, or lightning flash, leaps to the earth or to another cloud. The sudden expansion of air due to the great heat from the flash, and the rapid contraction as the air cools, are believed to cause the terrifying crash of thunder. When the lightning is some distance away, the sharp crashes of thunder are dulled and are changed to rolling sounds by echoes.

As condensation increases, tiny droplets of water grow larger and run together into drops that are too heavy to stay in the clouds. We feel cool wind, and we can see streaks of rain falling from the clouds. As the clouds move toward us, we feel the first splashes of rain. In a short time we are in the midst of a downpour. Sometimes the rising currents of air are very strong during thunder-storms and large hail-stones are produced. Local thunderstorms do not cover large areas, and we are often surprised to find that rain has fallen in one town and not in another that is near by.

FIG. 222. As the tip of a tornado moves along, it causes great destruction and often death. (Underwood and Underwood photo)

If a town is on the edge of a local storm area, it may even rain on one side of a street and be dry on the other side.

In spring, when there are great differences in the temperature, especially in the central United States, much more violent storms, known as *tornadoes*, are produced. The cause of tornadoes is not fully understood. But we do know that when tornadoes occur, slender currents of air rise with a violent whirling motion. The centrifugal force of these currents throws the air away from their centres. This makes the pressure very low in the centre of a tornado. We may recognize such storms by their funnel-shaped clouds that reach to the earth. Fortunately, the tip that touches the ground is small and covers only a small area.

There are two great sources of danger from tornadoes: (1) The winds may reach a speed of several hundred miles per hour, and (2) the suddenly lowered pressure on the outside of buildings may cause them to burst because of the greater pressure inside them. Luckily these storms do not last long. The rain that often follows is formed by condensation in the tornado. Tornadoes over oceans and seas are known as *waterspouts*. Scientists believe that they pick up little, if any, water. Great, violent storms, intermediate between the "lows" and the tornadoes, occur in tropical regions. They are called *hurricanes* or *typhoons*.

*Self-Testing Exercises.* 1. What kind of air movement usually causes a thunder-storm?

2. Why does hail sometimes accompany thunder-storms?

3. At what seasons are thunder-storms most frequent? Why?

*Problems to Solve.* 1. Read descriptions of tornadoes, waterspouts, hurricanes, and typhoons in some good book on weather. How are these storms caused? How are they alike? How do they differ?

2. Read to find more about lightning. Be ready to make a report to the class.

3. Scientists have found that sound travels about 1100 feet per second. During the next thunder-storm count the number of seconds between a flash of lightning and the time when you hear the thunder. Multiply this number of seconds by 1100, and you will know about how far away the lightning was.

## 3. How are weather forecasts made?

WHAT ARE THE CHIEF INSTRUMENTS USED IN WEATHER FORECASTING? Wouldn't you like to visit a weather station and see how the scientists there really find out about weather? Perhaps you have visited such a station. If so, you saw many kinds of maps and charts and many recording instruments. The "weathermen" did not even have to go outside to read the records from most of their instruments, for dials and records inside the building show what is happening outside. What kinds of weather-recording devices do weather forecasters need, and how do the men use their information to foretell weather?

One of the first instruments you would expect to find in a weather bureau is an accurate thermometer. Each station has one or more of these. There is also a kind of thermometer that shows the lowest temperature in twenty-four hours and one that shows the highest temperature. Each weather station also has a *thermograph* to record the temperature continuously for a week or longer. The thermometer of a thermograph is a coil made of two lengths of different metals fused side by side; the coil unrolls slightly when the air becomes warmer and closes when the air becomes cooler. (Why does it do this?) These changes in the coil raise and lower a long bar that carries a kind of fountain-pen. The pen makes a mark on a sheet of graph paper wound about a drum. The drum is turned at the correct speed by a clock, so that the pen makes a graph of the temperature record hour by hour for a week, in much the same manner that the *barograph* on the next page records the pressure of the atmosphere.

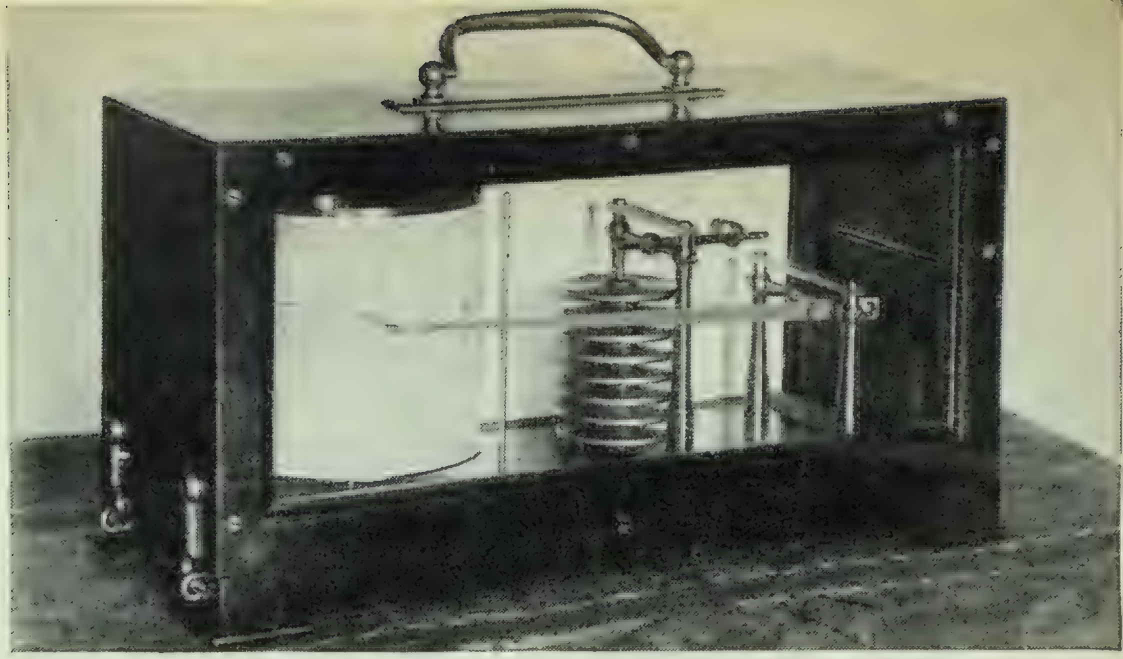


FIG. 223. A recording barometer, or barograph. The eight hollow, metal disks expand and contract with the changes in the air-pressure. What do you think is inside the disks? Why?

In the weather observatory you would find at least two barometers. The official readings are made with a mercury barometer. The meteorologist also uses a recording barometer, or barograph (Figure 223), that makes a graph of the air-pressure. The graph gives a continuous record of changes in air-pressure throughout the day. Weather forecasters must also know the direction of the wind and how hard it is blowing. For these purposes, a *wind vane* (Figure 224) electrically records the direction of the wind at frequent intervals, and an *anemometer* tells how hard the wind is blowing (Figure 224). Recording devices attached to the anemometer show the velocity of the wind in miles per hour throughout the day.

The amount of rain that falls is measured by a *rain gauge*. A rain gauge is a galvanized can with an opening ten square inches in area at the top. The "weather-man" measures the depth of the rain in the can by pouring it into a graduated glass tube. The depth of snowfall must be measured, too. This is done by pushing a measuring-rod, much like a ruler, straight down into the snow. Of course, a place has to be selected where the depth of the snow has not been changed by drifting. Scientists have learned that it takes an average of ten inches of snow to equal an inch of rain.

In addition to these instruments each station has a wet-and-dry-bulb thermometer for measuring the humidity. Some well-equipped observatories have a number of other, more complicated instruments. All of these instruments are located in places where their readings will not be affected by buildings, trees, or

other objects that might make them inaccurate.

If the station you visit is a large one, you may be fortunate enough to see the men sending up *pilot balloons*. These balloons are sent up four times daily. With a special instrument built for the purpose an observer watches the balloons as they are blown by the wind, and can estimate the direction and velocity of the wind high above the earth. Some stations send up balloons that carry automatic radio sending-sets known as *radio sondes*. To each radio set is attached an instrument that measures humidity, temperature, and the pressure of the air. The radio set sends these measurements to a receiving set in the weather station. When the balloon gets so high that it bursts, a parachute brings the instruments safely back to earth.

FIG. 224. The standard anemometer used in Canada has three metal cups set so as to turn the vertical shaft to which they are attached. It is connected by electric wires to the office below, where the number of revolutions per minute is recorded. At the left is a recording wind vane. (Trans-Canada Air Lines photo)

*Self-Testing Exercise.* Make a list of at least six kinds of information that weather forecasters get from their instruments. Opposite each kind of information write the name of the instrument or instruments.

*Problems to Solve.* 1. Make a wind vane.

2. Learn from reference books how the different weather instruments work. Find some kinds not mentioned in this book.

3. If you can obtain a thermograph record of temperatures throughout each day for one or two weeks, study it to find what time of day is warmest and what time is coolest.

HOW ARE WEATHER MAPS MADE? Weather forecasting in Canada is done by the Meteorological Service of Canada, a division of the Department of Transport. The headquarters of the Meteorological Service is at Toronto, and is shown in

FIG. 225. Measuring the depth of rain in the tube of a rain gauge

FIG. 226. Releasing a pilot balloon (T. C. A. photo)

Figure 204. There are also forecast centres at Halifax, Montreal, Toronto, Winnipeg, Lethbridge, Vancouver, and Victoria. Most of these forecasting stations are situated at the airports, and supply forecasts to the various companies that operate passenger and other air services. There are also about 125 smaller stations which report by telegraph two or three times daily. These extend from Nova Scotia to British Columbia, and from the international boundary to the shores of the Arctic ocean.

From information received by telegraph from stations all over the continent, weather maps, similar to that shown in Figure 217, are made four times a day at headquarters in Toronto, and at the forecast centres. For study of the weather, the maps show much more detail than that in Figure 217, and are used to make the forecasts that you read in the newspapers and hear on the radio. To make a weather map, a forecast centre must know the following things about the weather at each station: the pressure of the air, the temperature and dew point of the air at the time the report is given, the highest and lowest temperatures for the past twenty-four hours, the direction and velocity of the wind, the general weather condition (clear, partly cloudy, cloudy, fog, snow, rain), the height, amount, and type of cloud, the amount of rain that fell in the twenty-four hours before the report, the

FIG. 227. A forecaster of the Meteorological Service analyzes a weather map at Malton airport near Toronto. (T. C. A. photo)

character of pressure changes during the previous three hours, and other kinds of meteorological information.

A new weather map is made every six hours, and new forecasts for the various sections of the whole Dominion are made each morning and evening. New forecasts every twelve hours are necessary because the Meteorological Service cannot make forecasts for long periods of time, as the almanacs pretend to do by guesswork. As the weather information comes in over the teletype circuits from stations in Canada and the United States, and from ships at sea, it is recorded on a large map of North America. The forecaster draws isobars to connect points of equal pressure, and to locate regions of high and low pressure. He also sketches in the positions of cold fronts and warm fronts, and indicates the areas where precipitation is occurring. Now he has the information all spread out before him so that he can study it.

HOW IS A WEATHER FORECAST MADE? As you already know, the weather at any place is largely a matter of whether the conditions are those of a region of high pressure or low pressure and whether fronts are passing. The map shows the forecaster where the "highs," "lows," and fronts were at the time the information was collected. To predict the weather, the forecaster must decide in which direction the "highs," "lows," and fronts are likely to move and how fast they are likely to travel. He can

predict the direction and speed of movement of these conditions by noting how fast and in what direction they moved during the past 12 or 24 hours. Of course, the forecaster must be on the lookout for conditions which will cause the direction or speed to change in the future, and he must make allowance for expected changes. "Lows" may remain stationary for some time, or move only slowly. On the other hand, they may move at the rate of 700 or 800 miles in 24 hours. After the meteorologist has decided how these pressure centres are likely to move, he uses these basic facts to draw up his forecasts.

WHY IS THE WORK OF THE METEOROLOGICAL SERVICE IMPORTANT? The Dominion Government spends nearly a million dollars each year upon its weather services. Why should the government spend so much money on this work? Let us examine some of the ways in which weather forecasting helps people. Storm warnings are given all along the coasts and on the Great Lakes. These help ships at sea and people who live along coasts to protect themselves against storms. Stations in British Columbia issue cold-weather warnings in time for fruit growers and truck farmers to light smudge fires in their orchards (Figure 228) and to cover their young, tender plants. The Meteorological Service is worth its cost each year in the number of lives and the amount of property it saves.

In a similar way, long-distance shipping of farm products by truck and rail is aided by a knowledge of approaching weather conditions. For example, if a severe cold wave is coming, special care must be taken in shipping fruits and vegetables. In Canada, the various airlines do not employ their own meteorologists to issue forecasts for each flight. The forecasters of the Meteorological Service do this, as a very important part of their regular duties. In order to keep Canada's planes safely in the air, or on the ground when necessary, weather observations are made every hour and a half at about 40 stations across the country. From these observations, forecasts of weather likely to be encountered during flights are made. And what about yourself? When you are planning a picnic, a long automobile trip, or anything out-of-doors, do you not read the forecast in the daily paper or listen for it over the radio?

FIG. 228. Protecting fruit trees from frost

HOW MAY WE MAKE OUR OWN SYSTEMATIC WEATHER OBSERVATIONS? Not many of us are likely to have enough money to buy, nor enough experience and skill to install and use many of the instruments of the Meteorological Service; but a thermometer and a barometer are easy to obtain. These two instruments could be used to plan a school meteorological program.

Many weather observations may be taken without instruments. By looking out the window, one can tell if the rainfall is slight, showery, or heavy. Wind direction can be told from the drift of smoke just as well as by a wind vane. General weather conditions, such as rainy, cloudy, or sunny, can be observed simply.

You can, if you wish, by the use of the *wind rose* shown in Figure 229, study the types of weather that come with winds from various directions. For instance, if the smoke shows a west wind, and rain is falling, fill in a square on the "west" arm with a black pencil. If there are clouds, make the entry with, say, a purple pencil, and if sunny, with a red pencil.

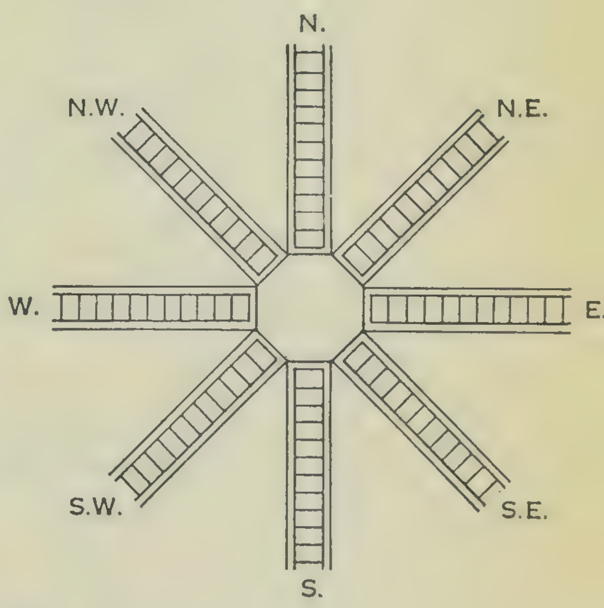



FIG. 229

You may judge and record wind speeds by the Beaufort scale (page 344), which has been widely used by meteorologists for many years. Amount of cloud may be measured in tenths. Thus, if the sky is half covered with cloud, you say that there are five tenths of cloud; if the sky is completely overcast, there are ten tenths. Be certain to notice and record unusual weather conditions and try to find an explanation for them.

## Beaufort Scale

| BEAUFORT NUMBER | GENERAL DESCRIPTION OF WIND | CORRESPONDING MOVEMENTS OF OBJECTS | LIMITS OF SPEED (M.P.H.) |
|---|---|---|---|
| 0 | Calm . . . . . . . . . . . . . . . . . . | Smoke rises vertically . . . . | 0–1 |
| 1 | Light air . . . . . . . . . . . . . . . | Wind direction shown by smoke drift, but not by wind vanes . . . . . . . . . . . | 1–3 |
| 2 | Slight breeze . . . . . . . . . . . . | Wind felt on face; leaves rustle . . . . . . . . . . . . . . . | 4–7 |
| 3 | Gentle breeze . . . . . . . . . . . | Leaves and small twigs in constant motion; wind extends light flag . . . . . . | 8–12 |
| 4 | Moderate breeze . . . . . . . . | Raises dust and loose paper; small branches are moved . . . . . . . . . . . . . . . | 13–18 |
| 5 | Fresh breeze . . . . . . . . . . . . | Small trees in leaf begin to sway . . . . . . . . . . . . . . . | 19–24 |
| 6 | Strong breeze . . . . . . . . . . . | Large branches in motion; whistling in telegraph wires . . . . . . . . . . . . . . . . | 25–31 |
| 7 | High wind . . . . . . . . . . . . . | Whole trees in motion. . . . | 32–38 |
| 8 | Gale. . . . . . . . . . . . . . . . . . . | Breaks twigs off trees; generally impedes progress . | 39–46 |
| 9 | Strong gale . . . . . . . . . . . . . | Slight structural damage occurs . . . . . . . . . . . . . . . | 47–54 |
| 10 | Whole gale . . . . . . . . . . . . . | Trees uprooted; considerable structural damage . | 55–63 |
| 11 | Storm . . . . . . . . . . . . . . . . . | Very rarely experienced; widespread damage . . . . | 64–75 |
| 12 | Hurricane . . . . . . . . . . . . . . | . . . . . . . . . . . . . . . . . . . . . . . | 75 and over |

*Problems to Solve.* 1. How many weather stations has your province? Find where they are located. What does the surface of the land and the size of your province have to do with the number of stations?

2. Get a recent weather map and compare the weather where you live with the kind of weather in Alaska on the same day.

3. Without reading it, cover the forecast on a recent weather map and make a forecast of your own. Then compare it with the forecast made by the weather-man.

4. Find how smudge fires protect orchards from frost.

5. How accurate are the forecasts in your locality? Clip the forecasts each day for two weeks or a month. Give the weatherman a grade for each day. At the end of the time average all of the grades. Your conclusions will be more accurate if several people do this exercise together.

FIG. 230. Trans-Canada Air Lines pilots study the weather map.

## Looking Back at Unit 10

1. Make a list of the different conditions that make up our weather, such as sunshine, etc.

2. Tell what you need to know in order to make a weather forecast from a weather map. Write your answers in complete sentences.

3. Give the meanings of these words:

| | | | |
|---|---|---|---|
| *warm front* | *"high"* | *"low"* | *humidity* |
| *altimeter* | *tornado* | *waterspout* | *cirrus clouds* |
| *radiant energy* | *thermograph* | *barograph* | *anemometer* |
| *water vapor* | *millibar* | *air mass* | *wind* |
| *cumulus clouds* | *dew point* | *barometer* | *stratus clouds* |
| *aneroid* | *fog* | *precipitation* | *isobar* |

## Additional Exercises

1. Keep a scrap-book of newspaper clippings that tell about unusual weather conditions. Try to explain their cause.

2. Find what causes mirages.

3. Find out why zigzag lightning differs from sheet lightning.

4. With the help of classmates or your science club set up a weather bureau. You can make most of your weather instruments. (See Pickwell's *Weather*, Chapter 6.) Subscribe for maps prepared by the Meteorological Service and issue weather reports each day.

5. Obtain some transparent paper. Place the paper over a weather map. Trace the word "Low" from the map. Then trace the circles

representing the different weather stations within one and one-half inches of the "low." Show the kind of weather at each station. Repeat this with eight or ten maps. Count the number of stations that show rainy or cloudy weather and the number that show clear weather. What do you find?

6. Repeat Exercise 7 for regions of high pressure.

7. If the air were not a freely moving material, it would not be warmed greatly even on a summer day. Explain.

## Books to Read

Boy Scouts of America. *Weather.* Boy Scouts of America, 1929.

Brigham, A. P., and MacFarlane, C. T. *How the World Lives and Works* (pages 50-88). American Book, 1935.

Brooks, C. F. *Why the Weather?* Harcourt, 1935.

Federal Writers' Project. *New England Hurricane: A Factual, Pictorial Record.* Hale, 1938.

Gordon, B. F. *Prove It Yourself* (pages 201-214). Owen, 1928.

Hawks, Ellison. *Book of Natural Wonders* (pages 72-92). Loring, 1935.

Heile, Maryanna. *The World's Moods.* Follett, 1930.

Humphreys, W. J. *Weather Proverbs and Paradoxes.* Williams and Wilkins, 1934.

Patch, E. M., and Howe, H. E. *Work of Scientists* (pages 29-61). Macmillan, 1935.

Pickwell, Gayle. *Weather.* Hugh F. Newman, 1937.

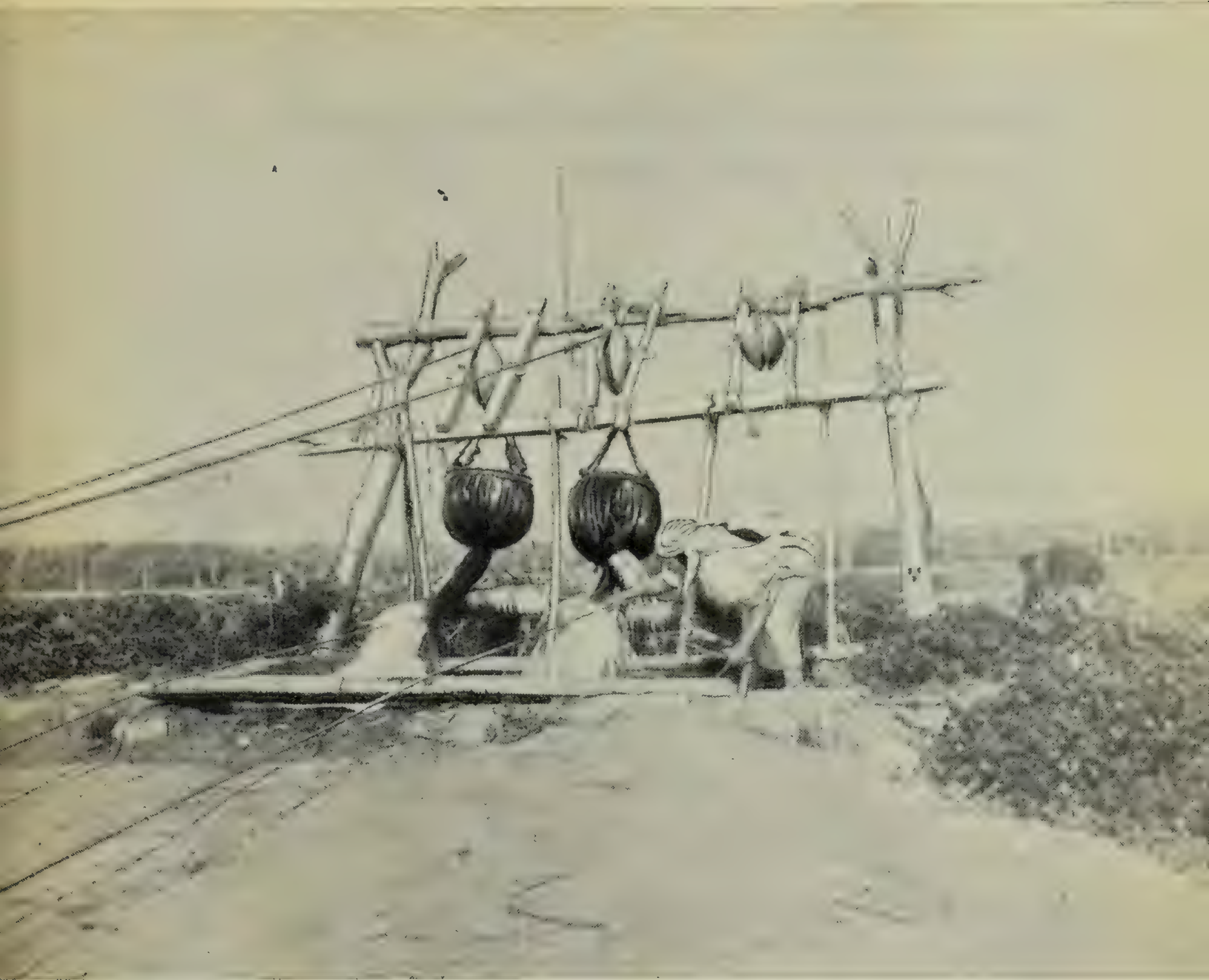
Reed, W. M. *And That's Why.* Harcourt, 1932.

Rogers, Frances, and Beard, Alice. *Fresh and Briny: the Story of Water as Friend and Foe.* Stokes, 1936.

Shenton, E. *Couriers of the Clouds* (pages 159-168). Macrae-Smith, 1936.

Talman, Charles Fitzhugh. *A Book about the Weather.* Blue Ribbon, 1935.

Van Cleef, Eugene. *Story of the Weather.* Appleton, 1939.



Obtaining a good supply of water is a problem that people must solve no matter where they live on this earth, for without water there can be no life. A journey around the world would show you many strange ways of getting this life-giving water. This picture shows a water-supply system in Tunis, Africa. From wells dug by hand the water is hauled up in leather bags. Camels pull the ropes that lift the water. Notice the crude pulleys over which the ropes run. (Herbert photo)

UNIT

11

# How Do We Provide Our Homes with a Good Water Supply?

## Looking Ahead to Unit 11

IT IS HARD TO REALIZE that there are only three things that we must have to stay alive. These three things are air, water, and food. We forget this because we have become so used to having so many other things that we think these other things are necessities, too. Everywhere on land man has been able to get plenty of air. But food and water are not always easy to get. Studies of the life of primitive people show that they lived in regions that were supplied with natural bodies of water such as lakes, rivers, and springs. It was probably an accident when men first discovered that water could be obtained by digging in the ground. This knowledge must have meant a great deal to people, for it made them independent of streams, lakes, and springs. They could wander farther from the natural bodies of water.

Until recently the shallow well dug by hand was the only method of getting water from the ground, but modern machinery has enabled us to bore into the earth to great depths. In this way people get water in regions where it was formerly thought that almost nothing could stay alive. The development of any region depends upon a source of water, for without water life cannot exist.

For those of us who have always lived in cities it is hard to appreciate what it means to have a supply of water on hand at all times. We are used to turning a faucet from which pours a stream of water to satisfy our needs. In some rural homes and rural towns, however, the problem is quite different. The water must be pumped by hand and carried to the place where it is used. In the winter the water in the pump may freeze and have to be thawed

FIG. 231. Glenmore Dam, Calgary (Canadian Engineer)

out before the pump will work. There is no water for the disposal of sewage, and it is difficult to have inside toilets.

To secure an adequate supply of pure water and to distribute the water so that it will be available whenever it is needed is one of the most important problems that a city faces. You can get some idea of the tremendous amount of water needed by large cities if you will study the figures in Table 15. How cities secure an adequate water supply you will learn in this unit.

TABLE 15. WATER CONSUMPTION OF CANADIAN CITIES

| CITY | POPULATION SERVED | GALLONS USED DAILY | GALLONS USED DAILY PER PERSON |
|---|---|---|---|
| Truro | 10,000 | 750,000 | 75 |
| Charlottetown | 14,000 | 1,280,000 | 92 |
| Regina | 55,000 | 3,950,000 | 72 |
| St. John | 64,000 | 16,000,000 | 250 |
| Edmonton | 90,419 | 7,132,000 | 79 |
| Ottawa | 147,954 | 14,200,000 | 113 |
| Winnipeg | 223,735 | 15,640,000 | 70 |
| Vancouver | 269,454 | 29,600,000 | 110 |
| Toronto | 649,123 | 74,280,000 | 114 |
| Montreal | 1,354,195 | 126,900,000 | 94 |

FIG. 232. *Aerators* like this one improve the condition of the water for use in a city. As the water is sprayed into the air, gases that cause bad odors and tastes can escape into the air. Also, the water can dissolve more oxygen. This dissolved oxygen helps purify the water as it flows through the pipes from the aerator to the homes.

In addition to the problem of securing enough water for daily needs, the quality of the water must be taken into consideration. The water should be clear, tasteless, and free from the germs which cause disease. Only a very few communities discover a near-by natural supply that fulfils all of these conditions. To be clear, the water must be almost entirely free from sediment. To be tasteless, it must not contain certain minerals and gases. To be free from germs, it must be guarded against pollution by materials, such as sewage, that may seep into it through the soil or that may wash into it from the surface of the land.

To secure such a water supply presents many problems. How can the purity of the water supply be tested? How can disease germs be kept out of the water supply? How can water be treated so that any germs present may be killed? All of these problems must be solved if a safe water supply is provided. After these problems have been solved, there still remains the important problem of distributing the water to the people of the town or city. How can an adequate supply of water be provided to all parts of the city at all times? How can the pressure of the water be kept up when large amounts of water are being used? How can reserve supplies of water be stored for emergencies?

After the water reaches the home, there is still the problem of controlling or regulating the stream of water so that it is available when and where we want it and the problem of disposing of the waste water. You know what the devices are for controlling the flow of water, but how do they work? How does a faucet control

the water? How do flush-tanks work? How is sewer gas prevented from entering our houses? How is hot water obtained? In this unit you will discover the answers to these questions.

## ¶ 1. How is a supply of water obtained?

WHAT ARE THE IMPORTANT SOURCES OF WATER SUPPLY? There are two principal sources of water supply, *surface water* and *ground water*. Both of these sources depend upon the rainfall and the snow. When rain, or any other form of water, strikes the ground, one of three things may happen to it: It may run off into streams, lakes, or ocean; it may sink into the ground; or it may evaporate into the air. A light rain falling in the forest or upon grasslands may nearly all soak into the soil. A heavy rain falling on the same land will run off, in part, into near-by streams because it cannot soak into the ground fast enough. The heaviness of the rainfall, the amount of vegetation, the slope of the land, the temperature of the air, and the kind of soil upon which the rain falls all determine what happens to the water. We are interested in the water that flows into the streams and sinks into the soil, because this gives us our water supply.

Let us first consider the rain that sinks into the ground and supplies the water for our *wells*. The questions we must answer are: "What becomes of this water?" and "How does it get into the holes that we dig in the ground?" A surprisingly large number of people cannot answer these questions. Many of them actually believe that our wells tap underground streams or bodies of water. You will soon discover that this is not true.

Some of the rain that sinks into the ground is held as a thin film around the particles of the soil. The remainder of it sinks downward until it comes to a layer of rock or soil which is *impervious* to water, that is, to a layer through which the water cannot pass. Since it can go no farther, it remains between the particles of soil above the impervious layer. This soil that has all the spaces in it filled with water is said to be *saturated*. The top of the saturated zone is the *water table* (Figures 233 and 234). The water table may be very near the surface or deep in the ground, depending on how far down the impervious layer is and


Fig. 233. Sometimes the impervious layer of rock or clay comes to or near the surface on hillsides, and the water flows out, forming a *spring*.

how much water has soaked into the soil. Since the ground water comes from the rain that soaks into the soil, the level of the water table varies at different seasons of the year. This is the reason some wells become dry during the summer months.

*Experiment* 55. HOW DOES THE WATER THAT SOAKS INTO THE GROUND GET INTO A WELL? (*a*) Fill a tumbler with small stones. Push a six-inch length of glass tubing down between the stones near the side of the tumbler to within a half inch of the bottom. Fill the tumbler about half full of water. How does the water get into the glass tube? How does the height of the water in the tumbler compare with that in the glass tube?

*b*) Put one-half inch of fine washed sand in the bottom of a large tumbler. With a piece of large glass tubing and some clay, build a "well" against the inside of the tumbler so that you can see into it from the side. Fill the tumbler with fine washed sand until it is within an inch of the top. Slowly pour some muddy water on the sand. With a long rubber tube draw out the first water that enters the "well." Then compare the clearness of the water poured into the tumbler with that of the water that seeps into the "well." Explain any difference you notice.

Water flows through the earth in the same way that it flows through the sand or gravel in the experiment. The water between the particles flows into the well until the level of the water in the well is the same as that of the water table. When water is taken from the well, more water runs in from the surrounding soil, sand, or gravel until the water in the well again stands level with the water table.

When the water table is reasonably near the surface of the soil, *shallow wells* may be dug by hand and walled up to keep the soil from falling in again. Modern wells of this type are con-

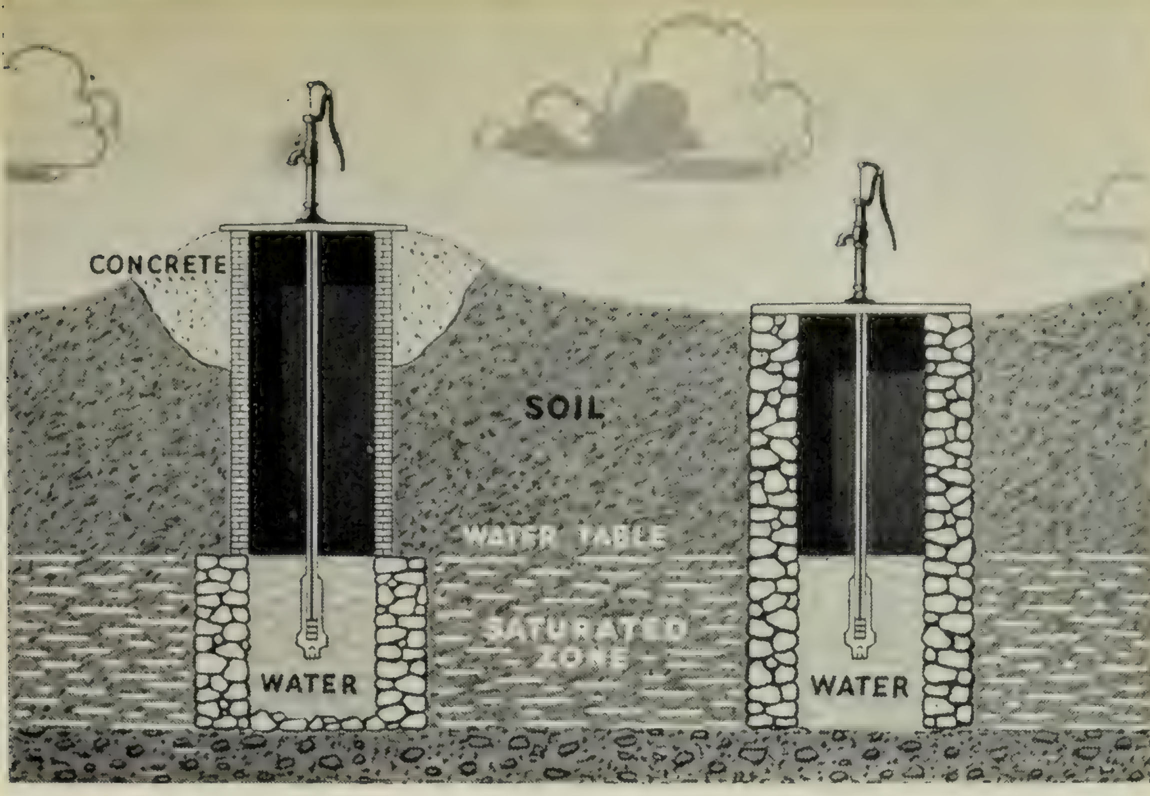



FIG. 234. The shallow well at the left is properly constructed to insure pure water. Notice that the wall above the water table is made of bricks cemented together, that there is a concrete *collar* around the top of the well, and that the land slopes down around the well. These three things keep surface water from getting in. The well at the right has poor drainage around the top, and the walls are merely loose stone.

structed of bricks cemented together by mortar. The water must either enter the well below the brick, or it must seep, or filter, through the brick. From part *b* of Experiment 55, you can see why the well with the cemented brick wall is superior to the well with the loose stone wall. The brick makes a filter to keep surface water, which is often impure, from getting quickly into the well.

The *driven well* is now taking the place of the old dug well to a considerable extent, especially where the water is found in layers of gravel or sand. To make a driven well, a *well point* (Figure 235) is screwed to the end of a pipe. This is then driven into the ground until it is below the water table. The well point has many holes in it, which are covered with a very fine screen. Thus the water can run into the pipe and be pumped up, the sand being kept out by the screen.

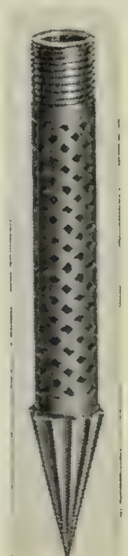


Fig. 235

In places where wells cannot be driven, they are usually *drilled* with powerful machines and lined with large steel pipes. Such wells are often drilled hundreds or even thousands of feet through solid rock and into layers of porous rock, such as sandstone, which contain water. Wells of this type are known as *deep wells*. In addition to the fact that there is much less danger of

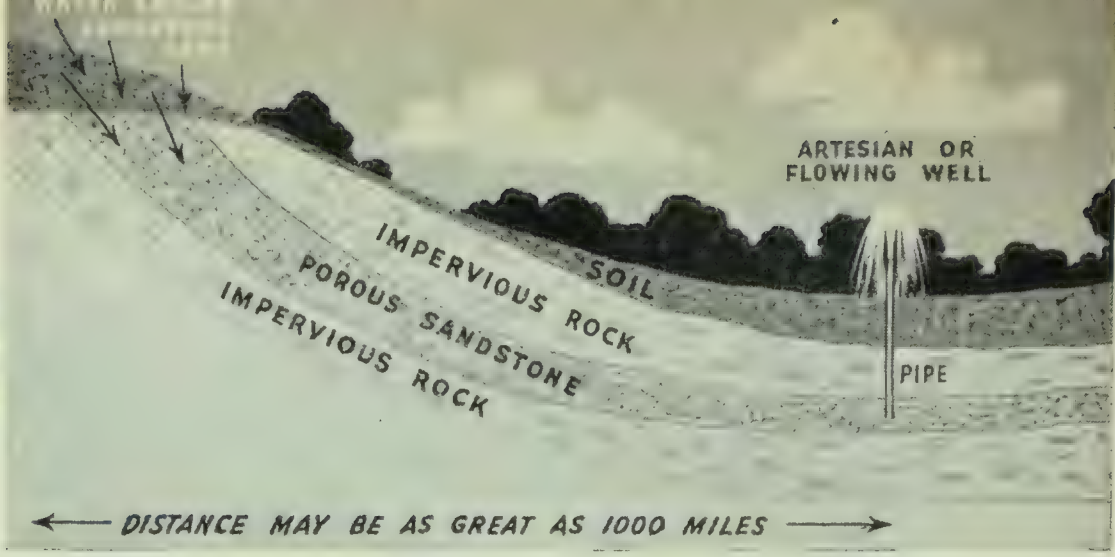



FIG. 236. If there is an artesian well in your neighborhood, try to find out how deep the well is and where the water enters the porous layer.

the water becoming impure, deep wells are not so likely to become dry during the summer as are shallow wells.

Water that enters the porous layer at a point much higher than the well may be under pressure and come to the surface or even spout into the air when the hole is drilled (Figure 236). Such wells are called *artesian wells*. Since the water must seep through many miles of porous sandstone, the impurities are usually filtered out. Water from deep wells and artesian wells is, therefore, usually safe for drinking purposes.

Most well water has the disadvantage of being *hard*. Do you know what makes it hard? Hard water is caused by the minerals that the water has dissolved from the soil and the rocks. You can tell hard water by the fact that it will not make soap suds easily. It is, therefore, quite common for country homes to have large underground tanks, called *cisterns*, in which to store soft rain water collected from the roofs of buildings. Although the water from cisterns does not usually taste good, it is much better for laundering and bathing. Some small cities get their water from wells or have wells to supplement the water from other sources. However, most large cities get their supply from surface waters such as are found in lakes, rivers, and small streams. A number of cities get their supply of water from the Great Lakes. These furnish an abundant and safe source if proper care is taken.

Mountain lakes and streams are usually the most satisfactory sources of water. The water from these sources is generally pure, and if it is obtained from high up in the mountains, pumps are not needed to bring it to the city. Many cities have bought huge areas of mountainous lands and have built dams and constructed

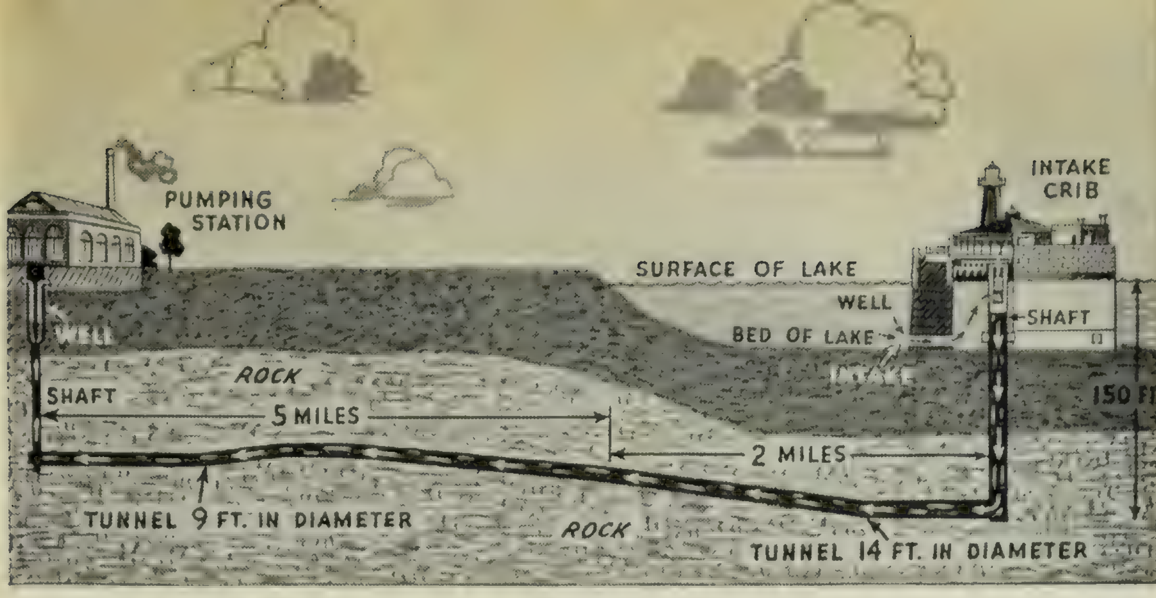



FIG. 237. In Toronto and other cities along the Great Lakes *cribs* are built out in the lake where the water is deep and practically free from impurities. Huge tunnels dug under the lake bottom bring the water to pumping stations on the shore, from which the water is pumped throughout the city. This diagram illustrates the Chicago plant.

reservoirs to hold the water which drains from them. New York City, not situated in the mountains, has bought over 900 square miles of mountainous land for this purpose. Los Angeles has tapped the Owens River, 250 miles away, and even the Colorado River, and has constructed huge pipes, or *aqueducts*, to carry water to the city. Many cities are able to get their water from rivers or other streams fairly near by. Water from these sources usually must be purified with great care.

*Self-Testing Exercises.* 1. Which of the sources of water mentioned in the problem will best meet the four requirements of a good water supply for a country home? Explain why the sources you have given for country homes will not meet the requirements for a city supply.

2. Explain what is meant by the water table. Be sure to include the saturated zone and the impervious layer in your explanation.

3. What makes the water come up in an artesian well?

4. What is hard water?

*Problems to Solve.* 1. Where does your water supply come from?

2. Find out about how far down the water table is where you live.

3. Why does spring water usually seem cold in summertime?

4. From your city water department find out what minerals there are in the water you use.

5. Read about artesian wells in some reference book and find out how far the water may travel before it comes to the surface.

6. Read in reference books about the water-supply systems of great cities such as London, Paris, Bombay, New York, Chicago, and Los Angeles.

How is ground water brought to the surface? Since the water in the ground is below the surface, it must, except in artesian wells, be brought up before it can be used. Pumps are usually used for this purpose. There are several kinds of pumps. The most common of these are called *lift pumps.* Figure 238 shows the principal parts of a lift pump. The *piston*, fitted with a leather washer to make it water-tight in the *cylinder*, is moved up and down by the *piston rod* when the pump handle is forced down and up. A *valve* (Valve 1 in Figure 238) is placed just below the pump cylinder, at the top of the *shaft*, or pipe, that goes down into the water in the well. There is also a valve (Valve 2) in the piston. Experiment 56 will help you understand the construction and operation of the lift pump.

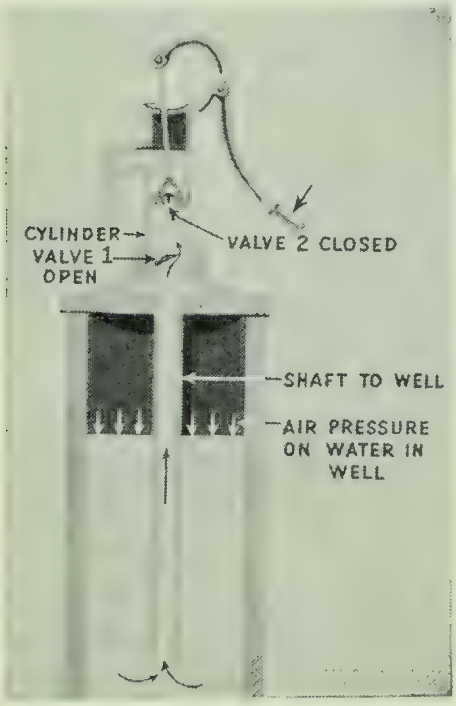



Fig. 238

*Experiment 56.* HOW IS A LIFT PUMP CONSTRUCTED AND OPERATED? (a) Obtain a glass tube one or two inches in diameter and twelve inches long. (A lamp chimney with straight sides will serve.) Fit a one-holed cork in the lower end. Cut a piece of rubber sheeting or oilcloth slightly larger than the hole in the cork. Place the rubber over the hole in the cork, fastening it at one side with a tack. This makes the lower valve (Valve 1, Figure 239). To make the piston, obtain a two-holed cork slightly smaller than the inside of the glass tube and wrap thread around it until it fits snugly inside the glass tube. Construct a valve of rubber sheeting or oilcloth over one hole in the piston. Into the other hole force a round wooden stick about 16 inches long, and fasten it securely to the cork by means of pins as shown in the figure. This forms the piston-rod. Now fit a two-holed stopper to the upper end of the glass tube. The piston-rod slides through one of the holes. Bend a glass tube six inches long into a right angle and insert this in the other hole. This makes the spout.

*b*) Push the piston down and pour a little water into the cylinder after loosening the upper cork. Place the cork in position again and

pull the piston upward. Does the lower valve open or close? Does the valve in the piston open or close? Observe that the water follows the piston upward. (It may be necessary to move the piston up and down several times.)

c) The space under the piston is now filled with water. Push the piston down. Describe the operation of the valves. How does the water get above the piston?

d) The water is now above the piston. Raise the piston and note which valve is open and which closed. How does the water get out?

You can now tell how the pump works, but can you tell why the water rises from the well when the piston moves upward? Water does not run uphill, nor does it rise in a pipe unless forced. Experiment 57 will help you answer this.


FIG. 239

*Experiment* 57. WHAT IS THE FORCE THAT MAKES THE WATER RISE IN THE PIPE? (*a*) Fit a test-tube with a one-holed cork. Insert a piece of glass tubing about two feet long in the cork so that it will extend down to the bottom of the test-tube. Fill the test-tube with water and insert cork. Apply your lips to the glass tubing and try to "suck" the water up into the glass tube. Do you succeed in doing this?

*b*) Loosen the cork so that the air can get into the test-tube above the water, and repeat what you did in part *a*. Does the water rise in the tube?

The experiment shows you that water will rise in a tube or pipe from which the air has been removed, provided the outside air can get to the water around the pipe. You have already learned that gravity is pulling the air covering of the earth down on to the earth with a force of about fifteen pounds on every square inch of the earth's surface (page 318). Of course, this air-pressure pushes down on the water in the well. The air presses down inside the pump also, but it presses against the top of the piston and not on the water below the piston.

The piston fits air-tight in the cylinder. When the piston is raised, there is left below it a space that contains only a little air; therefore the air-pressure in this space is very low. We say that

there is a *partial vacuum* in the pipe. (A *vacuum* means a space in which there is nothing.) The air-pressure on the water in the well, being greater than the air-pressure on the water below the piston, forces the water up from the well into the cylinder of the pump. Sometimes the piston and valves of a pump become so worn that the pump is no longer air-tight. Then water is poured in to fill the cracks so that the air can be removed from the pipe. This is called *priming* the pump.

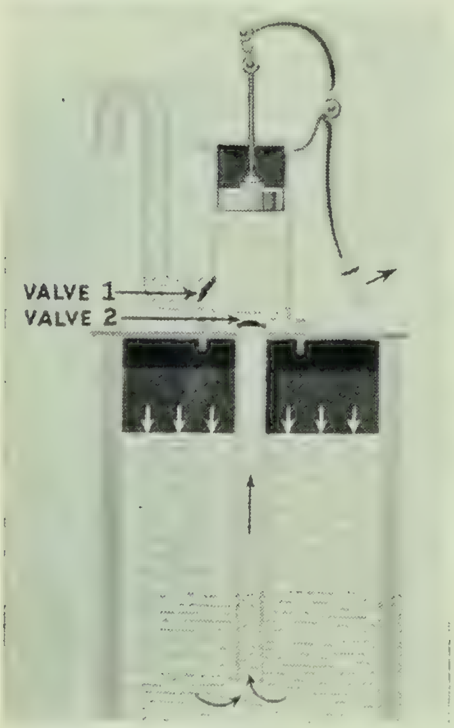



FIG. 240. A force pump

In the days of Galileo a nobleman had a pump put in a well that was more than forty feet deep. He was much disappointed when the pump would not deliver any water, although it was in good working order. Can you explain why water from the well did not reach the pump? Think of the experiment in which a tube with one end closed was filled with mercury and turned upside down (page 317). Atmospheric pressure held the mercury up only about thirty inches. Atmospheric pressure can push water 13.6 times as high as it can push mercury. In other words, atmospheric pressure will force water up about thirty-four feet into a perfect vacuum. Even a perfect pump will not work if its cylinder is more than about thirty-four feet above the water that it is to pump. As a rule, pump cylinders are not set more than twenty-five feet above the water. Can you see why?

When it is necessary to supply water at a level higher than the pump, *force pumps* are often used instead of lift pumps. The simplest type of force pump is shown in Figure 240. When the piston is pulled upward, Valve 1 closes, and water rises in the pump, forcing Valve 2 open, as in the lift pump. On the downward stroke of the piston, Valve 2 is closed by the pressure above it, and Valve 1 opens, allowing the water to be forced through the spout.

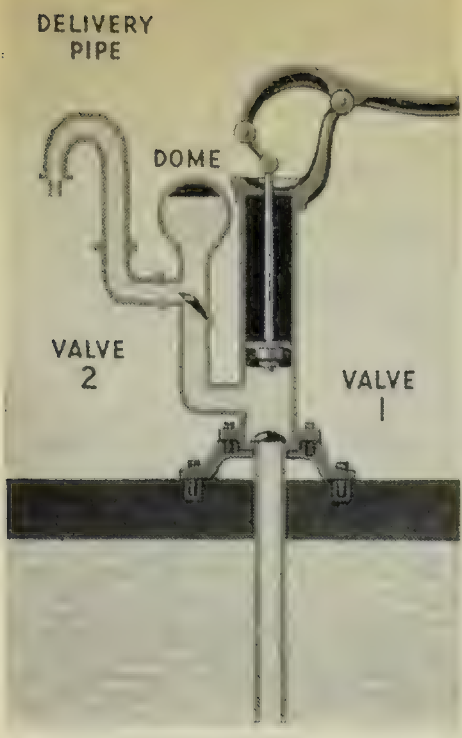



FIG. 241. Air-dome force pump

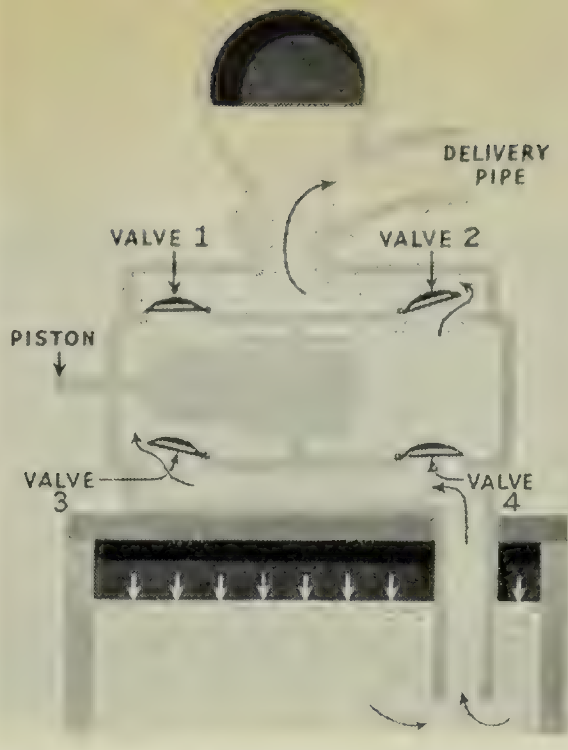



FIG. 242. A double-acting force pump

You have noticed that in the simple force pump the water flows from the spout only on the downstroke of the piston. When it is necessary to have a steadier stream of water from a pump, an *air dome* is added, and the spout is made smaller (Figure 241). As the piston moves downward, the water is forced through Valve 2 more rapidly than it can flow from the small spout. The air dome acts as a reservoir to hold the water that cannot get out through the spout while the piston is moving downward. Then, while the piston is moving upward, Valve 2 closes, and the air that has been compressed in the dome forces the stored water out of the dome and through the spout. In this manner a continuous stream of water comes from the spout during both the upstroke and the downstroke of the piston.

A *double-acting force pump* is sometimes used in city pumping stations and on fire-engines (Figure 242). It is really two air-dome force pumps fastened together so that water is being forced up into the pump and also out of the pump on both strokes of the piston; therefore a double-acting pump is able to pump water very rapidly and steadily. In Figure 242 the piston is moving to the right.

A different kind of pump, that is now widely used, is the *centrifugal pump*. You know how a whirling bicycle wheel or automobile wheel throws mud and water away from itself. The force that makes whirling things fly away from the centre is called *centrifugal force*. A centrifugal pump uses this force together

with atmospheric pressure to pump water. Figure 243 shows how this kind of pump works. It has a circular case in which a paddle wheel, or *impeller*, is made to spin very rapidly. The rapid spinning throws the air or water toward the outside of the pump and creates a partial vacuum in the centre of the case. One pipe leads the air or water away from the outside of the case, and another pipe lets water into the centre of the pump. Atmospheric pressure on the water around this inlet pipe pushes the water up into the pump. Since water is more dense than air, it is more easily thrown out by the paddle-wheel; therefore this kind of pump is often primed with water to make a better vacuum when the paddle-wheel is first started whirling.

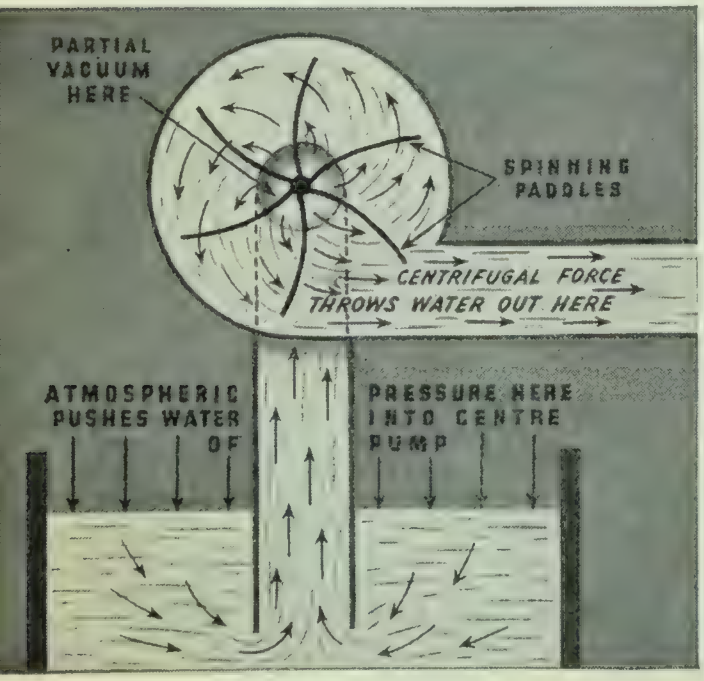



FIG. 243. A centrifugal pump

*Self-Testing Exercises.* 1. Figure 238 shows the piston on the upstroke. Make a drawing of this figure to show the positions of the valves and the movement of the water on the downstroke.

2. Figure 240 shows the piston on the downstroke. Make a drawing to show position of pistons and movement of water on the upstroke.

3. Draw Figure 242 and show the positions of the valves and the flow of the water when the piston moves to the left.

4. Write a paragraph in which you make clear the characteristic that is common to all of the pumps described.

5. Name the kinds of pumps that can produce a steady stream of water. Explain why in each case.

*Problems to Solve.* 1. In a driven well that is very deep the piston must be placed deep in the ground. Why? Make a drawing showing the location of the different parts of a pump in a deep well, and explain how the water is brought to the surface of the ground.

2. Submerge a small glass tube in a pan of water. Place your finger tightly over one end and remove the tube from the water. Why does the water remain in the tube?

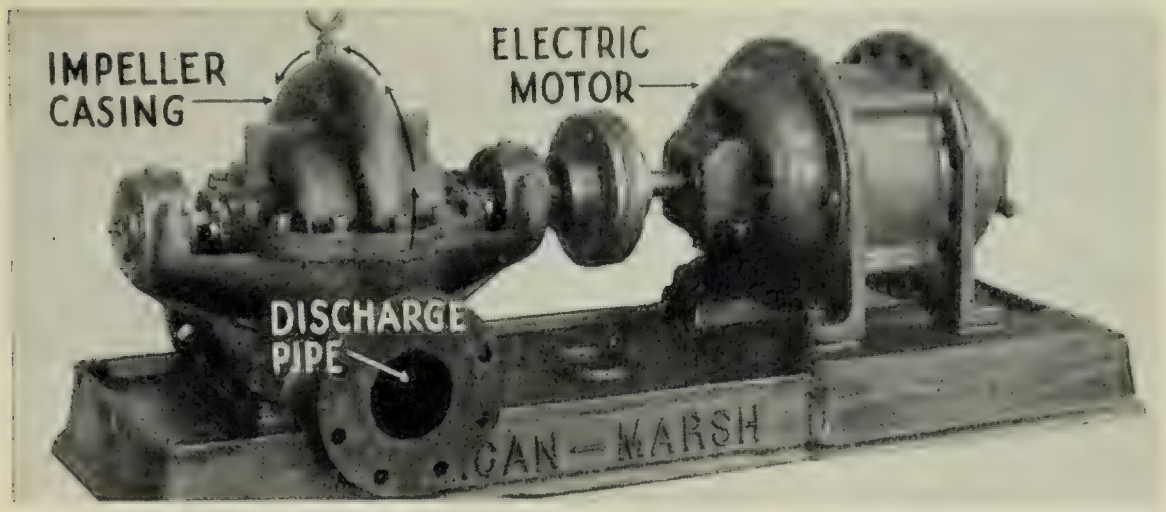



FIG. 244. Centrifugal pumps can move water faster for their size than any other kind of pump. They are often used in automobile cooling systems, in city water-supply systems, on fire-trucks, and in the basements of skyscrapers to fill the water tanks at the different levels in the buildings.

3. Find as many ways as you can of lifting water without the use of pumps.
4. Find out what kinds of pumps are used in your town's pumping station and on its fire-engines.
5. Find out what *hydraulic rams* are and how they lift water.
6. How can a siphon lift water up over an obstacle and carry it down the other side?

## 2. How is the quality of the water supply maintained?

HOW IS THE SOURCE OF OUR WATER SUPPLY PROTECTED? You have probably heard the old saying, "An ounce of prevention is worth a pound of cure." In obtaining a water supply this should be the "Golden Rule," for our water supply is easily polluted with disease germs unless the proper care is taken. There are three main sources of pollution: (1) wastes from human beings and animals, (2) decaying plant and animal materials, and (3) garbage. Wastes from human beings and animals are most dangerous, for they may contain germs of such diseases as typhoid fever, cholera, diarrhoea, and dysentery.

Shallow wells that are improperly constructed or located are common sources of danger. Figure 234 on page 353 shows you a poorly made well and one constructed the way it should be. In rural districts or in very small towns the common outdoor

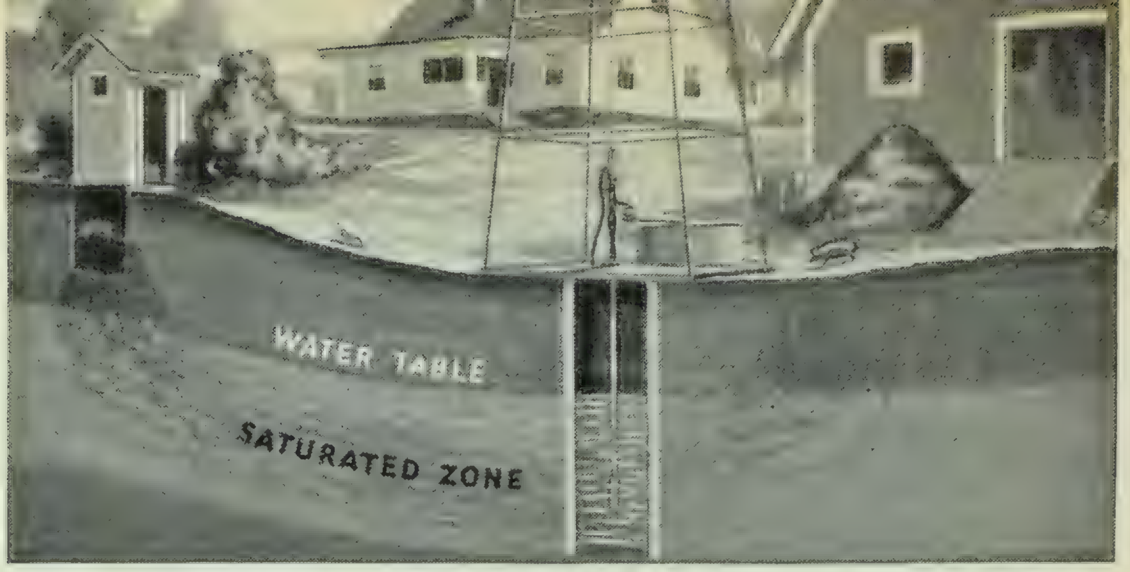



Fig. 245. This well has three sources of contamination: the surface water running into the top of the well, especially during a hard rain; the cesspool draining toward the well, and the barnyard draining toward it.

toilet, or *cesspool*, may be a very dangerous source of pollution of well water. The cesspool is merely a hole in the ground, ten or twelve feet deep and four or five feet in diameter. This is usually lined with stones. If it is used, the cesspool should be at least fifty feet from the well, and it should drain away from the well. If you study Figure 245 for a moment, you can see what happens when the cesspool drains toward the well.

A safer way of taking care of home sewage is the *septic tank*. A septic tank is made of concrete (Figure 246). In this device the solid materials are decomposed by bacteria and changed to liquid. This liquid passes from one section to another, and by the time it leaves the septic tank it is colorless and odorless.

But even in a city it is a very difficult problem to safeguard the water supply, because in most instances the source of supply is surface water. Cities that get their water from rivers and lakes must prevent, if possible, the discharge of sewage and wastes into the water within certain distances from the city. Most cities get the water upstream from where they empty their sewage, but they do not always consider the danger to other communities located downstream. The purity of the water supply depends largely on the proper disposal of sewage. A modern and scientific method of

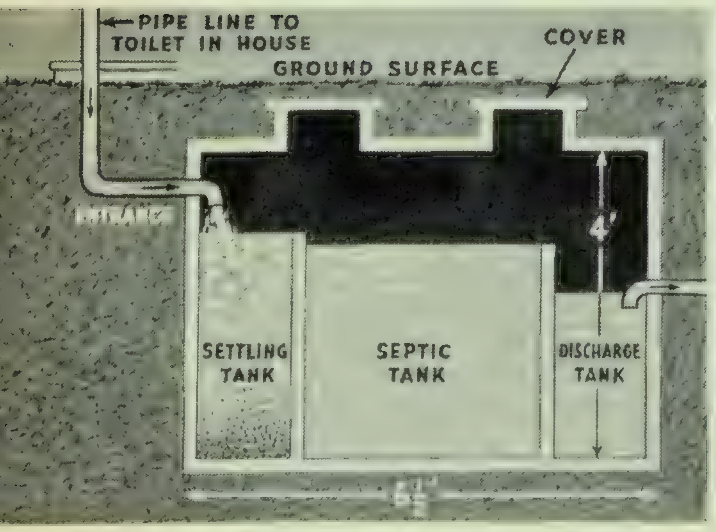



Fig. 246. A septic tank


FIG. 247. One kind of large-city sewage-disposal plant. The sewage is carried by large pipes from the homes and buildings to the pumping station. It is then pumped to the aerator, where it is sprayed into the air. It falls back into a basin filled with broken stone. As it trickles over the stone, it is decomposed and purified by bacteria that grow in a thin layer on the stones. The sewage then goes into a basin, where the solid parts settle. The liquid part is filtered through sand to remove any impurities that may be left.

sewage disposal is shown in Figure 247. As a necessary measure of safety, the water supply should be regularly tested for disease-producing germs.

*Self-Testing Exercises.* 1. Why is the problem of sewage disposal in a city much more complicated than in a rural home?

2. Explain fully what Figure 245 shows about the pollution of a water supply.

*Problems to Solve.* 1. Find out how your own city or town disposes of its sewage. Does it seem to be a safe way?

2. How do bacteria help in sewage disposal? Refer to page 362 and read reference books to find out.

HOW IS WATER PURIFIED? If you live in a city that gets its water from a river, you have perhaps wondered how the muddy water in the river can be made fit for drinking. The water in the river may contain all sorts of impurities, such as decayed animal and vegetable matter, sewage from towns along the banks, and disease-producing germs. Yet this water may be made perfectly safe for human use by a number of different methods. Perhaps the commonest method of removing impurities from water is filtration.

*Experiment 58.* HOW ARE IMPURITIES REMOVED BY FILTRATION? Tie a cloth over the bottom of a lamp chimney and support it on a tumbler, as you did in Experiment 33, page 156. Pour in some coarse


Fig. 248. A sand water-filter for a large city. The layers of sand and gravel are made very thick so that the water trickles through slowly. (From *Compton's Pictured Encyclopedia*, F. E. Compton & Co., publishers)

sand to make a layer about two inches thick. Now pour in fine sand within an inch of the top. Make a mixture of muddy water and pour it in at the top of the chimney. What change takes place in the water?

Figure 248 shows a type of sand filter commonly used by many cities. Analysis of the water that runs through such a filter shows that soil particles and practically all disease-producing germs are removed by this process. Figure 249 shows a filter that may be used in the home. The water is forced by the pressure in the water system through porous porcelain that removes all impurities.

Another practical method of purifying water is storing it in a reservoir for several weeks. Impurities floating in the water, such as soil particles, slowly settle to the bottom, and the water becomes clear. This does not mean that the water is yet pure, for the clearest water may contain many disease germs. However, because the reservoir is uncovered, the germs are destroyed by the sunlight and by the oxygen dissolved in the water. In cities where the water as it comes from its original source is very muddy, it is necessary to purify it by another method.

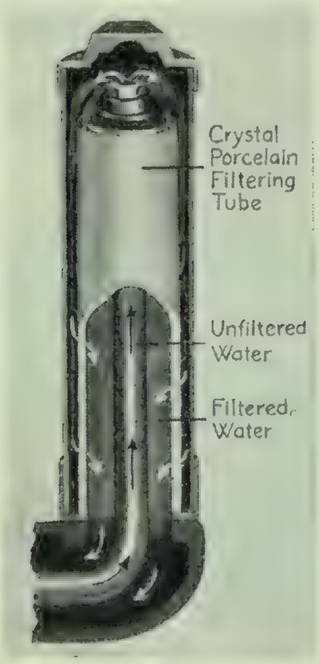



Fig. 249

*Experiment* 59. HOW CAN MUDDY WATER BE CLEARED? Fill two small bottles with muddy water. Put a small quantity of alum solution in one bottle. Allow the two bottles to stand, and observe the changes that take place in the appearance of the water in each bottle. After twenty-four hours note which bottle contains the clearer water.

Fig. 250. Water is pumped from the Saskatchewan River into the settling basins at Saskatoon, where some of the impurities settle to the bottom. Now refer to Figure 251.

The alum forms a great many sticky flakes in the water. As they form, they get larger and larger, until they become heavier than water. Then they sink to the bottom. Thus they collect almost all of the bacteria and particles of mud, carry them to the bottom, and leave the water quite pure and clear.

In cases where the water supply is badly contaminated, some other method of killing the disease-producing germs must be used. In some cities this is done by putting into the water a small amount of *chlorine* gas or of bleaching powder which kills the germs. These materials are objectionable in that they give the water a peculiar taste if they are used in large quantities. Another way of making sure that the water is free from disease-producing germs is to boil it for half an hour, but of course this cannot be done for whole towns or cities.

Cities that must use very impure water quite commonly remove the impurities by a combination of methods. In one widely used plan the water is allowed to run into great settling basins where more than half the mud may settle to the bottom. The clearest water near the surface is then led away, treated with alum or iron sulphate, as in Experiment 59, and allowed to settle a second time. Again the surface water is led away, this time to be filtered through sand in order to remove the remaining flakes of alum with the mud and bacteria which they have collected. To make sure that no disease germs escape, a small amount of chlorine is usually added to the water before it is pumped to the homes. If there are bad odors and tastes in the water, aeration basins, as shown in Figure 232, may be included in the series of purification processes.

FIG. 251. This is one of the settling basins shown in Figure 250. Note the enormous amount of mud which has settled from the water and which the workmen are removing. The sediment has settled from the muddy waters of the swift-flowing Saskatchewan.

Sometimes water that is to be used for special purposes must be completely freed from its dissolved minerals, as well as from all other impurities. Distillation is the only method that will remove both kinds of impurities. Distilled water is suitable for chemical experiments and for other uses that require small amounts of very pure water. But of course the process is much too slow and expensive for use with a city's supply.

*Experiment 60.* HOW DOES DISTILLATION REMOVE IMPURITIES FROM WATER? Construct an apparatus as shown in Figure 39, page 76. Use a cork stopper for the flask. Fill the flask one-fourth full of muddy water containing two or three teaspoonfuls of salt or sugar and some ink. Heat the flask. When the water begins to boil, turn the flame down so that the water will boil slowly. Notice the drops of water that collect in the delivery tube and in the test-tube. Examine the water in the test-tube. Taste it. Are there still minerals in the water, or have they been removed from the water?

The methods of purifying water that you have been studying show how water may be freed from disease germs, sediment, and bad tastes and odors. Practically all natural waters, with the exception of rain water, contain minerals dissolved out of the rocks and soil. Some of these minerals do not harm the water supply, but certain minerals, such as calcium or magnesium sulphate, make the water undesirable for several uses. When a water containing these minerals, that is, hard water, is used in boilers to make steam, the minerals remain in the boilers and form a hard

deposit called *boiler scale*. This scale causes the boiler to heat unequally, and also increases the amount of fuel needed to heat the water. Hard water is also undesirable for laundry purposes, as you will see in the following experiment.

*Experiment 61.* WHY IS SOFT WATER MORE DESIRABLE THAN HARD WATER FOR LAUNDRY PURPOSES? (*a*) Make a soap solution by placing Ivory or Castile shavings in a bottle of rain water or distilled water. Add shavings until no more soap will dissolve after the bottle is well shaken.

*b*) To a test-tube half full of distilled water or rain water, add the soapy water made in part *a* drop by drop (use a medicine-dropper), shaking after each drop. (The test-tube should be stoppered or covered securely with the thumb, while shaking.) When a layer of lather about one-half inch deep remains on top of the water for a minute, the test is complete. How many drops are necessary to make this lather?

*c*) Repeat part *b*, using, instead of distilled water, water from a well or from the city supply. Compare the amount of soap required to make a lather with the amount required for the same volume of distilled water.

*d*) Make up some very hard water by dissolving some calcium sulphate or magnesium sulphate in water. Repeat part *b*. Hold the test-tube up to the light and note the tiny flakes in the water. Compare the amounts required in parts *a*, *b*, and *c*. Conclusion?

The next question is, "Why does it take more soap to make suds with hard water than it does with soft water?" When soap was added to the hard water in part *d* of the preceding experiment, your attention was called to the white flakes that were formed. These flakes were formed by the combination of the soap with the minerals in the water. The new materials that were formed were not soluble in water; so they separated out as solids. Chemists say that such insoluble materials are *precipitated*, because they settle to the bottom. Before the soap would form suds, all of the minerals that caused the soap to precipitate had to be removed. After this was done, the soap could form suds and remove dirt.

Fortunately, the water supply of many cities is soft enough for laundry purposes. In a few cities whose water supply is hard, water-softening plants have been established to remove the un-

desirable minerals. If this is not done, the water must be softened if the people are to get full value from the soap they use.

*Experiment 62.* WHAT EFFECT DO BORAX, WASHING-SODA, AND AMMONIA HAVE UPON HARD WATER? (*a*) For use in this experiment make some hard water as in part *d* of Experiment 61. Take one-half test-tube of this water and determine the number of drops of soap necessary to make a lather.

*b*) Add a pinch of borax to the same volume of water. What is formed? Determine the number of drops of soap necessary to make a lather after the borax is added.

*c*) Repeat part *b*, using a pinch of washing-soda. Compare the results with those in part *b*.

*d*) Repeat part *b*, adding about five drops of strong ammonia water. Compare results with those in part *b*.

*e*) Summarize the results of this experiment.

*Self-Testing Exercises.* 1. Summarize the methods used in purifying water. First, list the impurities which must be eliminated, and then give the methods used to eliminate each kind of impurity.

2. Explain what hard water is and how it may be made soft.

*Problems to Solve.* 1. If possible, visit the water plant in your town and find out exactly how the water is purified.

2. If you were on a camping trip and were not sure that the water you could get was free from disease germs, what could you do to make the water pure?

3. How can the crew of a ship prepare fresh water out of sea water? How does nature do it?

## ¶ 3. How is water delivered to the consumer?

IN SUPPLYING WATER FOR A CITY it is, of course, necessary to distribute the water from the source to the consumer. This is accomplished by sending the water through a series of large *water mains* with side branches, or *laterals*. These mains are sunk five or more feet below the surface of the ground. At this depth the temperature remains almost the same at all seasons of the year; hence there is no danger from freezing. A connection is then made for each building with the lateral main. Of course, there must be pressure on this water to make it run through the mains and laterals and up into buildings.

Two hundred years ago horses worked the pumps that slowly filled London's small reservoirs. The system was so primitive, that householders were allowed to run the water only twice a week or so for an hour; when a disastrous fire broke out in St. James's Palace, there was only one thin stream of water from the Thames to put it out.

Probably the simplest way of keeping up the pressure is to make use of the force of gravity. Cities near high mountain ranges often build dams across the mountain streams. The water fills the reservoir above a dam and runs into the upper end of a huge pipe, or aqueduct, which leads down to the water mains of the city. The place where the water runs into the pipes is so much higher than the city that there is always a great deal of water in the pipes above the faucets. Gravity is pulling downward on all the water; therefore in all the lower parts of the system there is a great pressure which forces the water out of the pipes. When you open a faucet, the water rushes out.

FIG. 252. This large water tower holds 1,500,000 gallons of water. (Ewing Galloway photo)

Towns, factories, and country homes that are not near hills or mountains use gravity to produce pressure by building elevated reservoirs or standpipes of various types. Some are steel cylinders with straight sides (Figure 253); others are small tanks or reservoirs held up in the air by a steel framework (Figure 252). These reservoirs are usually filled by pumps that take the water from a lower source. Why are these reservoirs usually in the highest place available?

*Experiment 63.* HOW HIGH WILL WATER RISE IN PIPES CONNECTED WITH A RESERVOIR OR STANDPIPE? Connect a long rubber delivery tube to the bottom of a large pail or can. Do this by punching a hole in the bottom of the can, putting the tube through a stopper, and fitting the stopper into the hole. Place the jar on a high table or cabinet several feet above the level of the sink or open window.

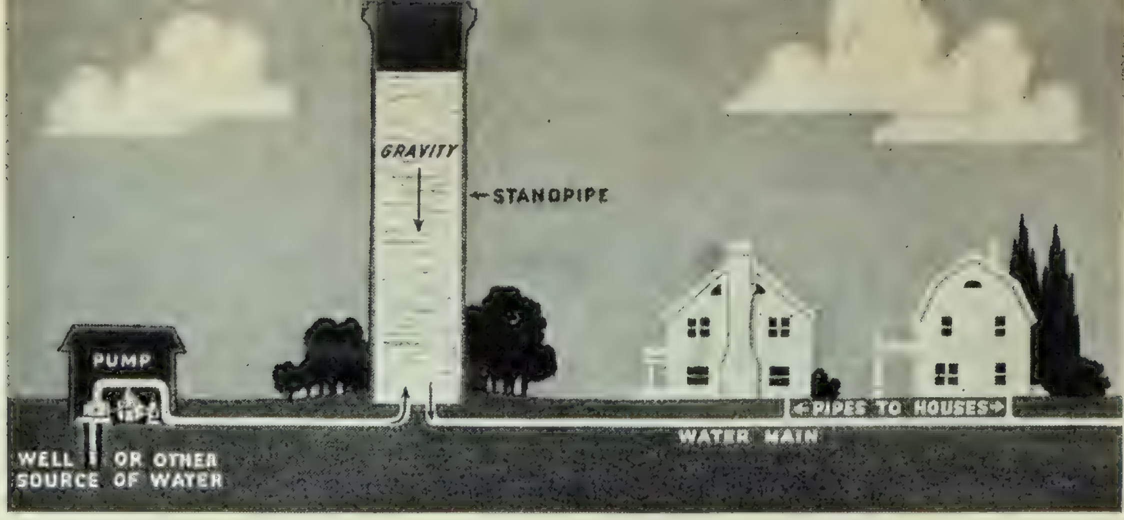



FIG. 253. How a pumping station and a standpipe are used to supply water to buildings

Close the end of the delivery tube with a clamp, or bend the tube so that the water cannot flow through it. Fill the jar with water. Attach to the end of the delivery tube an upright glass tube three-eighths or one-half inch in diameter and long enough to reach above the level of the water in the jar. The jar represents a reservoir or standpipe, and the delivery tube a water, or service pipe.

*a*) Open the pinch clamp slowly. How high does the water rise in the delivery tube?

*b*) Substitute for the large glass tube one of smaller diameter. Repeat part *a*. Does the diameter of the water main determine how high the water rises?

*c*) Substitute for the large jar a much smaller jar and repeat part *a*. Does the diameter or volume of a reservoir determine the height to which the water rises?

*d*) Summarize the results of this experiment.

A second method of keeping up the pressure in the pipes is used in many large cities. Huge pumps are connected directly to the water mains and are run continuously. The pressure can be regulated by the amount of power applied to the pumps. When there are thousands of homes and factories using water from the pipes, the number of faucets being closed at any one time will be about the same as the number being opened. Thus the amount of water needed does not change greatly from minute to minute, and the pumps can keep the pressure quite even.

A combination of pumps and gravity is used when the pumps are unable to keep up the pressure, or the source of supply does not furnish enough water during the rush hours. A standpipe or reservoir is connected to the water mains of the city. During the hours when little water is being used, the pumps fill it up with the unused water. Later, when the pumps cannot furnish enough

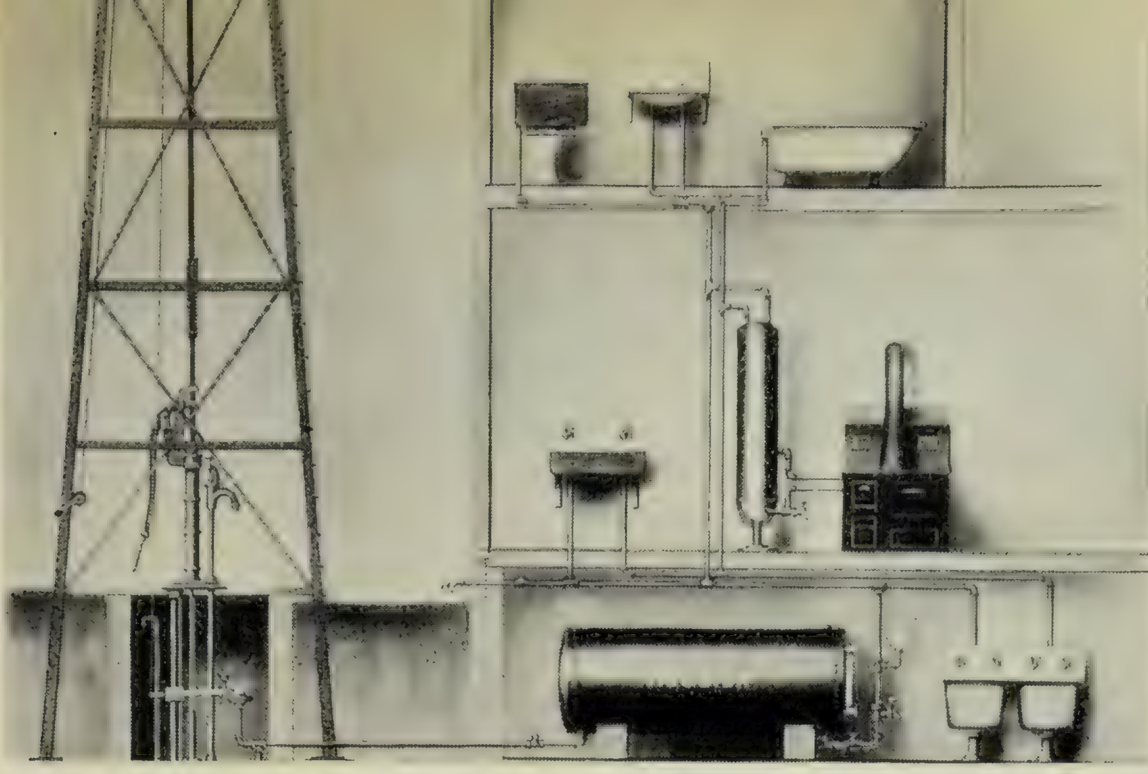


Fig. 254. This *pneumatic-tank* water-supply system is operated by power from a windmill. A gasoline engine or an electric motor could, of course, be used just as well to provide the power.

water because so much is being used, the water runs from the reservoir into the mains and helps keep up the pressure. Such reservoirs are also of great value when extra water is needed because of a fire or a "breakdown" of the pumps.

Cities that have very tall buildings cannot be expected to supply pressure enough to make water reach the upper floors of such buildings. Even if they were able to do so, the pressure at lower levels would be too great to be conveniently controlled. Pipes and faucets would have to be made much stronger than is necessary. To reach the top of a skyscraper in New York or Chicago, water must be under a pressure of more than 300 pounds per square inch, while the ordinary city pressure is not more than 50 pounds to the square inch. Such buildings have individual water-pressure systems. Pumps are placed in the basement, and reservoirs are located at various levels throughout the building to give the correct pressure on all floors.

Still another kind of pressure system, known as the *pneumatic-tank*, or air-pressure, system, is very convenient for buildings not connected with a city water supply. A large tank is placed in the basement and connected to a force pump and to the water pipes of the building (Figure 254). The pump forces water into the tank in such a way as to compress the air inside. This compressed air keeps up the pressure after the pump stops and forces the water up through the pipes to the faucets.

*Self-Testing Exercises.* 1. Under what circumstances would a city use (*a*) the pull of gravity to produce the force necessary to distribute the water, (*b*) a pumping system, and (*c*) a combination of pumping system and reservoirs?

2. From what you learned in Experiment 63, tell whether (*a*), (*b*), (*c*) or (*d*) correctly completes this statement: The height to which water from a reservoir will rise in a delivery pipe depends on

a) the size of the reservoir.
b) the diameter of the delivery pipe.
c) the amount of water in the reservoir.
d) the height of the reservoir.

*Problems to Solve.* 1. A housewife finds that water flows with greater force from the faucet at midnight than at midday. Explain.

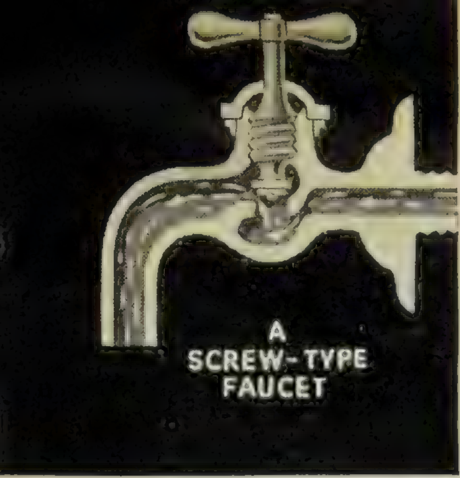
2. Why do pipes often burst when the water in them freezes?

3. What kind of pump works on the same principle as the pneumatic-tank system shown in Figure 254? Explain.

## ¶ 4. How is the supply of water controlled in our buildings?

TO CONTROL THE FLOW OF WATER some device is necessary to open and close the pipes. Where the water has been used for washing purposes, the waste water must be carried away. To obtain hot water it is necessary to provide some method of heating the pipes that deliver the water to the hot-water faucet. To show how certain devices do these things is the purpose of this problem. To understand how a device operates you must first see clearly the purpose for which the device is used. Second, you must examine it, or a drawing of it, to see how it is made. Third, you must see what changes take place in the position of the various parts during its operation; and fourth, you must understand how these changes in position make the device work.

HOW DO FAUCETS AND FLUSH-TANKS CONTROL THE FLOW OF WATER? In order that the water may not be wasted, we must have some devices to turn it on and off when we use it. This is commonly done by means of *faucets* and *flush-tanks*. Figure 255 shows a section view of the commonest type of faucets. As you can see, in the screw-type faucet, the usual kind we find, the handle is attached to a screw that fits into the upper part



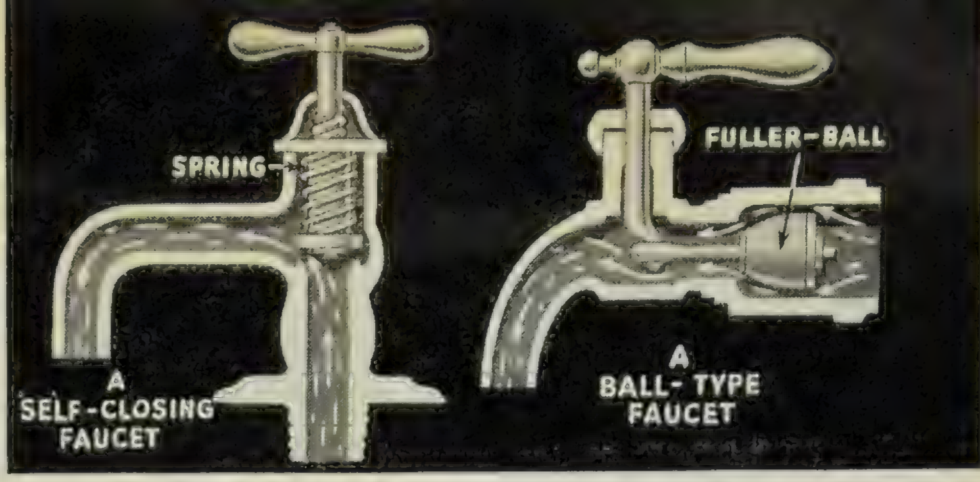




FIG. 255

FIG. 256. Self-closing and Fuller-ball faucets

of the faucet. The lower end of this screw is usually faced with a flat fiber or leather washer. This flat washer covers the circular opening, or *seat*, at the bottom. If the handle is turned, the washer is raised, and the water can flow through the opening. When the faucet is turned off, the screw forces the leather washer down against the opening, and the water is shut off.

The handle rod usually has some *packing* of cotton twine around it. Sometimes this packing gets loose and the faucet leaks. Also, after a time the washer may become worn, and the water will trickle out. It has been estimated that a trickle only one sixty-fourth inch in size will waste seventy gallons of water per day. In order to prevent this waste of water, all of the working parts of the faucet must be kept in good condition. It is very easy for any boy or girl to repair a leaky faucet in a home. After turning off the water in the basement, it is necessary only to remove the handle with a wrench and either tighten the packing or replace the old worn washer with a new one. Sometimes the seat becomes so worn that the washer cannot be made to fit it tightly. In such case a new faucet must be obtained.

In our houses we are careful to see that the faucets are not left open, but in hotels and in other public places much water is wasted if the screw type of faucet is used. To control this, self-closing faucets have been invented. Figure 256 shows this type of faucet. When the handle is turned, the screw causes the plunger to move upward, compressing the spring. The spring forces the plunger back when the handle is released, shutting off the water. In another common type of faucet the flow of the water in the faucet is controlled by a ball of rubber which presses tightly against the opening (Figure 256). This is known as a *Fuller* ball. When the handle is turned, the ball is pushed backward, and the water flows through the opening. It is fairly easy to repair a faucet of this type. What part would you replace?

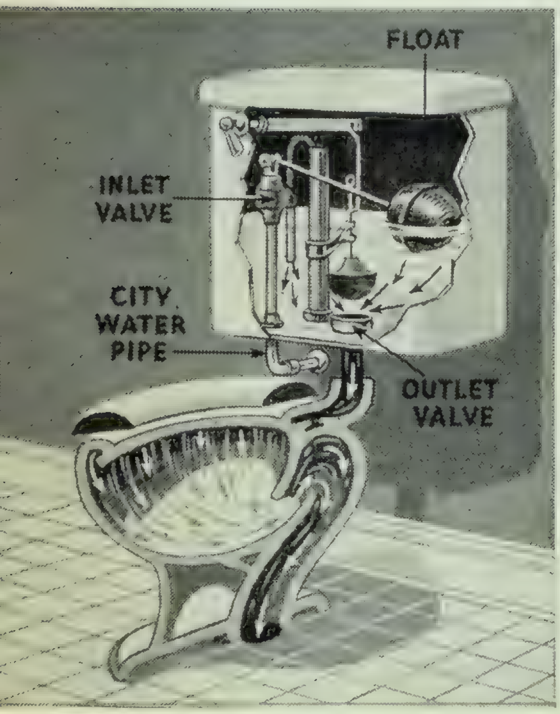



FIG. 257

One of the necessary sanitary devices for controlling the water supply in the house is the flush-tank, connected with the toilet (Figure 257). The flush-tank is generally located on a pipe above the toilet, but in some cases it is built into the wall. If you remove the lid of the tank, you see a hollow copper ball about four inches in diameter. This ball floats on the water. By pulling on a chain, pressing a button, or turning a lever, the outlet valve is opened, and the tank empties into the bowl. As the water sinks, the copper ball sinks with it and opens the inlet valve, which is attached to the other end of the rod connected with the ball. The outlet valve slowly sinks back into position and closes the opening into the bowl. Then the water enters and fills the tank. The copper ball rises with the water, closing the inlet valve when the tank is full, and the tank is again ready.

At times, on account of their worn condition or improper adjustment, the valves may not completely shut off the flow of water into the tank or into the bowl. While the flush-tank is refilling, a special pipe pours enough water into the bowl to prevent the sewer gas from entering the room.

*Self-Testing Exercises.* 1. Make a list of the possible causes of leaky faucets and tell how you would repair them.

2. Make a drawing of the flush-tank, showing the position of the various parts when the float-ball is down. If you can remove the lid of the flush-tank in your house, do so. Operate the lever or chain and observe what happens inside the tank.

HOW IS HOT WATER SUPPLIED? A very common appliance for obtaining hot water is the *storage tank* connected with the kitchen range (Figure 258). The storage tank is supplied from the water-supply system, the water entering the tank at the top. A pipe connects the tank with a coil of pipes, or a *water-front,* in the fire box of the stove. Another pipe carries the hot water back to the storage tank.

*Experiment 64.* HOW IS THE WATER IN THE STORAGE TANK HEATED? (*a*) Obtain a straight glass tubing three-eighths of an inch in diameter and about three feet long. Bend as shown in Figure 259. (Straight tubes connected with rubber tubing can be used if desired.) Obtain a bottle with the bottom cut off or a straight lamp chimney, fit a two-holed cork in one end, and arrange the apparatus as shown. Drop some sawdust thoroughly soaked in water into the tubes and also into the bottle. Fill the apparatus with water.

*b*) Heat one tube of the apparatus by moving a small flame rapidly up and down the lower part of the tube at the corner marked +. Notice carefully whether the height of the water in the bottle increases. Why should it increase? Note the movement of the water as shown by the sawdust. Does the cold water move up or down? How does the warm water move?

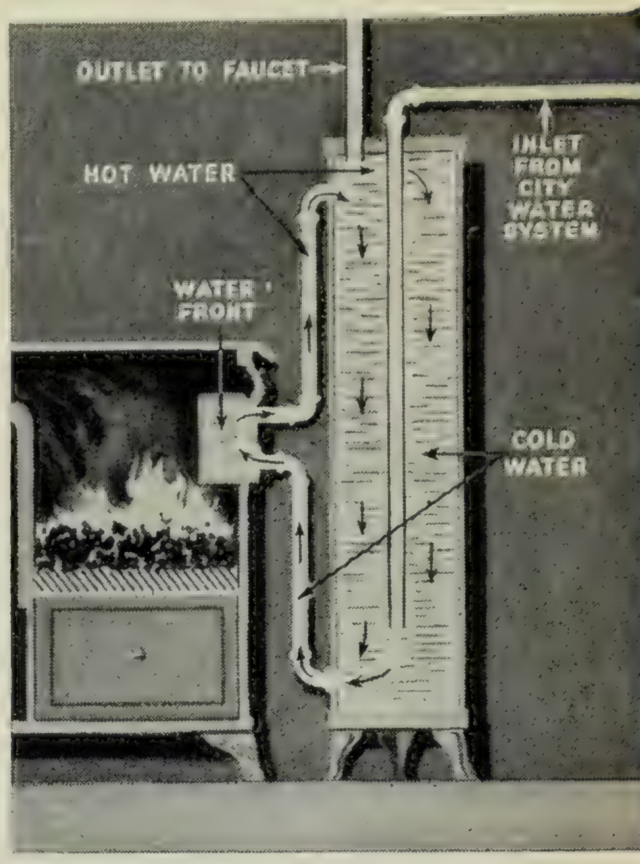



FIG. 258

In many buildings heating coils are placed in the fire boxes of furnaces to furnish hot water. These coils are usually connected with a storage tank. Hot water collects in the storage tank during all the time that there is a fire in the furnace. Then, when much hot water is needed for bathing or for washing clothes, it can be drawn rapidly from the hot-water faucets. This type of hot-water supply has the same disadvantage as the kitchen-range water supply; namely, hot water can be furnished only when a fire is burning in the heater.

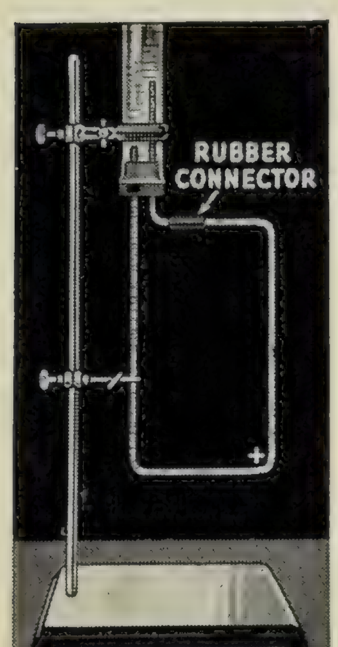



FIG. 259

The most satisfactory hot-water supply is obtained in houses that are connected with artificial or natural gas. The heater usually consists of a coil of copper water pipes surrounded by an iron jacket and connected with a hot-water tank (Figure 260). The heat from the flame passes upward and cir-

culates around the coils of water pipe. Because the pipe is in coils, there is a large amount of surface that is exposed to the flame; therefore the water is heated very quickly.

The gas is burned inside of the jacket at the base of the heating coils, and the size of the flame is controlled automatically in this way: At the bottom of the storage tank is a copper tube, which expands when heated and contracts when cooled. This copper tube is connected with the gas supply. When the water is cold, the tube contracts and opens the gas valve. As the water is heated, the tube expands and closes the valve. A small pilot-light is always left burning, and the heater needs no attention. With the automatic gas heater hot water is always available, and the amount of fuel burned depends upon the water used.

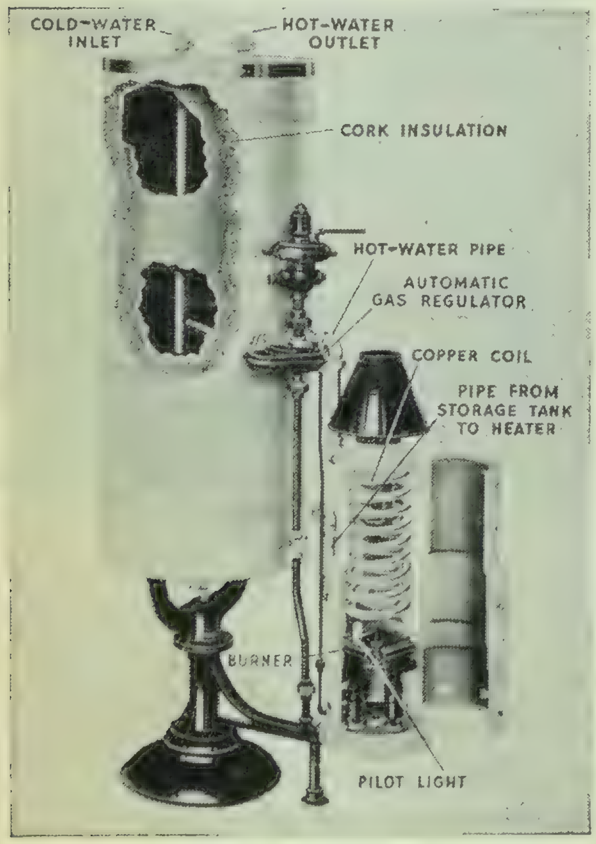



FIG. 260

HOW IS WASTE WATER REMOVED? Another problem in the control of water in the house is the removal of the waste water. Every house that is supplied with city water must also have a drainage system. Figure 261 shows the plumbing in a modern residence. You will notice that below each bathtub or sink there is a curve in the pipe. This curve, or *trap*, is always full of water. The purpose of these traps is to keep sewer gas out of the house. Sewer gas forms in the sewer pipes from the decay of waste materials in the sewage. This gas has an unpleasant odor and is dangerous. One sewer pipe, called the *soil pipe*, extends above the roof to let the sewer gas blow away in the air. If it could not escape in this way, it might bubble into the house through the water in the traps.

Sometimes the traps get filled with grease or other materials, and the water will not flow out. Concentrated lye or boiling water frequently poured into the drain usually keeps the pipe clear. Cans of material specially prepared for this purpose may be purchased at hardware and grocery stores. In case solids get lodged in this

trap, another remedy is used: A small plug that is usually placed in the lower bend of the trap is unscrewed, and the materials are taken out.

*Self-Testing Exercises.* 1. Explain how a coil or water front that holds only a little water can heat all the water in a forty-gallon tank.
2. How does gravity help a hot-water supply system work?
3. (*a*) What is the purpose of a water trap in a drain pipe? (*b*) Why does one pipe extend above the roof?
4. How can you clean a trap that has become clogged?

*Problems to Solve.* 1. Suppose someone said to you, "The hot-water supply system depends upon differences in the density of water in the tank." How would you explain what he meant?
2. Draw a house similar to Figure 261 but with a different arrangement of rooms. Put in the plumbing fixtures and connect the pipes properly. Label all the important things shown.

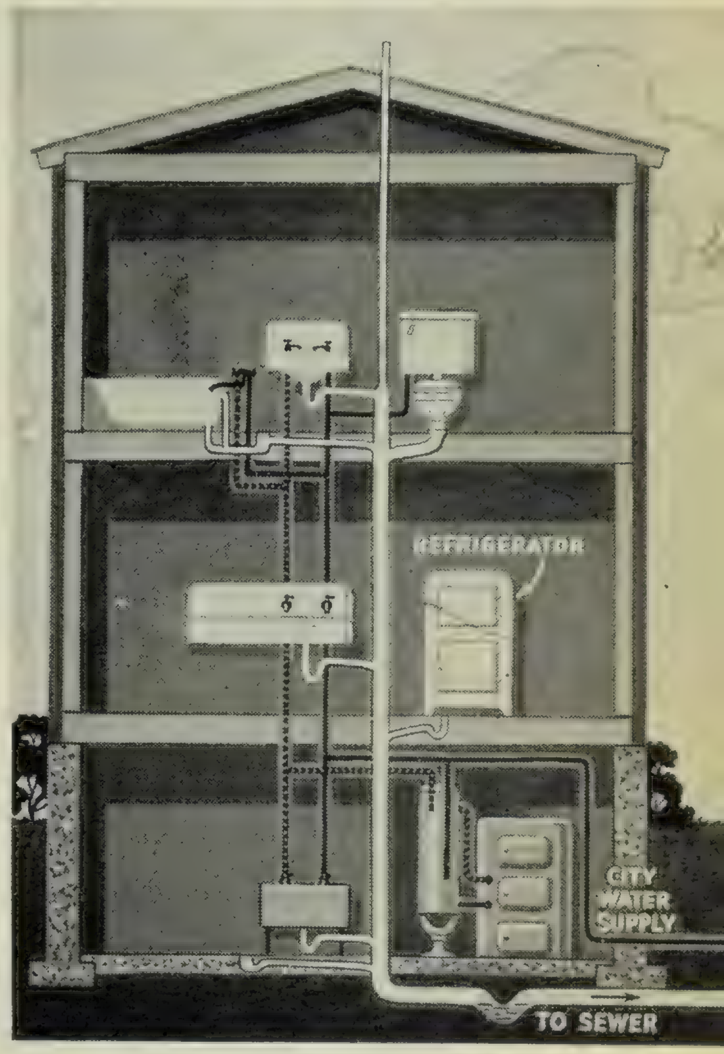


FIG. 261

## Looking Back at Unit 11

1. Make a list of all the principles, or big ideas, of science that you have learned from your study of this unit. State each principle in sentence form.
2. Explain what each of these words or phrases means:

| | | |
|---|---|---|
| *ground water* | *centrifugal force* | *force pump* |
| *vacuum* | *hard water* | *distillation* |
| *lift pump* | *saturated soil* | *driven well* |
| *septic tank* | *water table* | *aqueduct* |
| *prime (a pump)* | *artesian well* | *impervious* |

## Additional Exercises

1. What parts of the flush-tank are most likely to get out of order?
2. Why do some wells and springs go dry at certain seasons?

3. Mountain streams usually furnish a pure water supply. Why?

4. Why is cistern water sometimes dangerous to drink? What impurities may it contain?

5. Why does a layer of white material, or scale, often collect in the bottom of a tea-kettle?

6. Why is it not a good practice to drink from streams in country districts?

7. Cisterns are sometimes constructed so that a brick wall divides the cistern into two parts. The water from the roof of the house flows into one side of the cistern, and the water for the house supply is drawn from the other side. What is the advantage of this method of construction?

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USING THE ENERGY OF EXPLODING GASES instead of the energy of human muscles, this machine does in one day the work of hundreds of men. It is a complicated machine with hundreds of parts. Yet, strange as it may seem, this complicated machine is made up of only four or five kinds of simple machines such as you probably use every day. In this unit you will learn that no matter how big or complicated a machine may be, it is made up of only a few simple machines that you have known about almost ever since you began to play with toys. You will also learn just how and why these machines help people do work. (Empire photo)

# UNIT 12

# How Do Simple Machines Help Us Do Work?

## Looking Ahead to Unit 12

When you saw the title of this unit, you probably thought of such machines as gasoline engines, sewing-machines, reapers, steam engines, and electric motors. But if you read the title again, you saw that it said *simple* machines. Perhaps you changed your mind, then, and thought of lawn-mowers, food choppers, and can-openers. If you did so, you were still guessing. The simple machines of science are different from what you think. The scientist uses the word *machine* for any device or tool that man uses to help him do his work. A gasoline engine is very different from a screw-driver, but they are both used to help him do work. So the scientist calls each of them a machine.

However, the scientist sees that machines are quite different in the way they work. So the scientist goes one step further and puts together into one class the kinds of simple devices that work alike. For example, most can-openers and bottle-openers really work just like a crowbar, or a hammer pulling a nail, or the jaws of a pair of pliers. The scientist therefore puts all of these devices and many others into a single class of simple machines that he calls *levers*. When you learn how a lever works, you can then explain how any of the many kinds of levers work.

In this unit you will learn that scientists have divided all simple machines into six different classes. When a scientist speaks about simple machines, he means a machine that belongs to one of the six classes that you will learn about. Hundreds of tools and devices that we use can be explained if you understand how each of these classes of machines helps man in his work. The more complicated machines, such as the crane, steam-shovel, and printing-press, are combinations of many simple machines belonging

FIG. 262. When a hammer drives a nail into a board, it is one kind of simple machine. When it is used to pull the nail out, it is another kind of simple machine. (Starek Studios)

to different classes. But even these complicated machines can be explained by seeing how each class of simple machine helps in the operation of the complicated machine.

In this unit you will think chiefly about the simple machines that are put together to make complicated machines of all kinds. You will find the answers to questions that have come to your mind as you have watched work being done in various ways. You have probably seen a man rolling a heavy barrel up a plank into a wagon. Perhaps you have seen *pulleys* used to pull up the stump of a tree or lift several bales of hay into a haymow. By himself a man could not lift the barrel or the bales of hay. But by using a machine he can easily move these heavy loads. In other words, he can lift objects that are very heavy by using a much smaller force. How is this possible? Do these machines really increase the amount of work that we can do?

What you learn about machines in this unit will be of practical value to you. Once you understand how a simple machine helps you, you can use it more intelligently. You will know what kind of work it can do and what to expect of it. You will learn how to select the kind of simple machine you need for the kind of work you want to do. Girls sometimes get the idea that machines are only used by boys. But that is not true. A girl may use simple machines in her home more often than a boy. Everybody uses machines. You will also see that we should have a hard time getting along without them.

FIG. 263. This short steel bar and a block of wood make a lever that is being used to lift a heavy block of concrete. (Starek Studios)

## 1. What are machines used for?

YOU HAVE JUST BEEN READING about some of the ways in which machines help us do our work. Let us take a few examples of the uses of machines and see exactly how these machines help. We will first suppose that there is a large stone in your garden and that you wish to move it. It is too heavy for you to lift. The easiest way to move it is to place the end of a strong pole under one side of the stone and a brick under the pole near the stone. Now if you push down on the outer end of the pole, you find that by using a rather small force (as compared with the weight of the stone) you can easily lift the stone. How did this machine help you work? With the long bar you were able to lift a heavy weight (the stone) with much less force than you would have needed if you had used your muscles without the pole. This is one of the great advantages of a machine. With the help of a machine we do not need to use so much force.

There are many kinds of machines used for this purpose. With the proper kind of jack, a small child can lift an automobile weighing thousands of pounds. Pump handles, claw-hammers for pulling nails, nutcrackers, wheelbarrows, can-openers, sloping planks, tack-pullers, pliers, wrenches, and jack-screws are all simple machines by means of which we can use a small force to overcome a much larger resistance. This may be clearer to you if we say that with machines of this type we can multiply our force; that is, by using a force of ten pounds, a person can lift objects weighing a hundred or a thousand pounds.

Did you know that when you fish with an old-fashioned bamboo fishing pole, you are using a machine? Let us see why a fishing pole is a machine and how it helps do work. Usually you hold the end of the pole in one hand next to your body. Then you pull on the pole with the other hand. Your hand moves only a few inches, but the other end of the pole moves many feet. Furthermore, it moves much faster than your hand, so that the fish is brought quickly above the surface of the water before it has a chance to get away. In this case the weight is moved farther and faster than the force. The machine has thus multiplied the distance travelled by the weight and the speed at which it travelled. Derricks used to lift and swing loads from one place to another are machines that multiply speed (Figure 264). Your own arm, as you will see later, is a machine that works in the same way.

Still another way in which machines help us is by changing the direction of the force that is being exerted. Did you ever see a load of bricks being lifted to the top of a high building by a rope running over a wheel? This arrangement of a rope and a pulley allows the person doing the lifting to stand on the ground and pull downward to make the load move up. The pulley changes the direction of force and makes it more convenient to lift the load. A bicycle is another example of a machine that changes the direction of force; you push down on the pedals to make the bicycle pull you for-

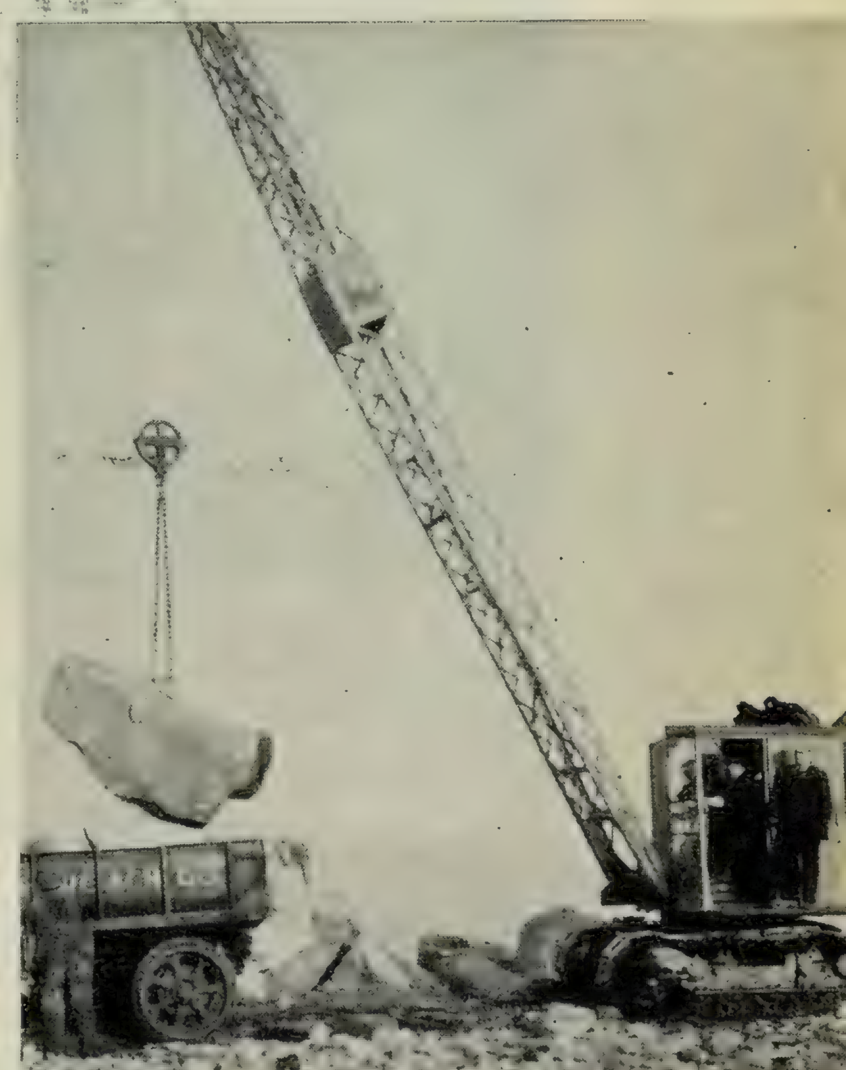

Fig. 264. The engine pulls down, but the rock moves up. Also, the lower end of the derrick moves through a distance of only a few feet, while the upper end moves many feet. (Empire photo)

ward. The gear wheels in a rotary egg-beater make the blades turn in one direction as you turn the handle in another direction. As you study this unit, look for other machines that change the direction of the force.

You can now see that machines help us do work in three important ways: (1) They may multiply our force. (2) They may multiply our distance and speed. (3) They may change the direction of the force.

FIG. 265. Later, in Unit 19, you will learn how a big gear wheel like this multiplies speed.

*Self-Testing Exercises.* 1. Describe an experience of your own in which you used a machine to move a large weight with a much smaller force.

2. Make a diagram to show that in a fishing pole the force you apply to pull up the pole moves a much shorter distance than the fish. Also explain why the fish moves faster than your hand.

3. Make a diagram of some machine that you have used or seen that changes the direction of the force.

*Problems to Solve.* 1. How does a hammer help us pull nails?

2. Examine each of the pictures of machines in this unit. Write the name of the machine and then tell how the machine helps do work; for example, it may multiply our force.

## 2. Why do machines help us do work?

HOW IS WORK MEASURED? If you have been thinking during your study of this unit, you have probably wondered *why* a machine makes work easier. To understand why you can lift heavy weights, drive nails in boards, bore holes in wood, and do other things with machines that you could not do without machines, you will need to find out what the scientist means by *work*, and how he measures work. When you want to measure

something, you must have some unit of measurement. For example, you measure distance by such units of length as the inch, the foot, the yard, the rod, and the mile. You measure the amount of heat in a body by calories. You measure the hotness of a body by its degree of temperature. In a like manner, we need a unit to measure work.

First of all, you must be certain that you understand what the scientist means when he uses the term *work*. To do work you must, of course, use force; that is, you must push or pull some object. Suppose that you lift a stone from the ground. You exert a force on the stone, and you lift the stone against the pull of gravity. The scientist would say that you have done work. Suppose, however, that the stone was very heavy, and that although you used all the force you could, still the stone would not move. Would you call this work? You probably would, but the scientist would not. In order to do work, you must do more than use force. You must actually move the object. Work is done only when a force overcomes some resistance and thus moves something.

You do work when you pedal a bicycle, drive a nail, pull a sled, or lift a basket of groceries from the floor to the table. Some of these, riding a bicycle, for example, may have seemed more like play than work to you. But you did some work in each case. When you ride a bicycle, you overcome the friction of the bicycle wheels and of the air. When a nail is driven, the blow of the hammer exerts a force in making the nail push the fibres of the wood apart and move down into the wood. When you pull a sled, you move its weight a certain distance; and when you lift an object, you move its weight through a vertical distance from the floor to the top of the table.

In these examples of work nothing has been said about *how much* work was done. In other words, you have no unit to measure how much work is done when a stone is lifted from a floor. We usually measure force in pounds. If a stone weighs ten pounds, you must use a force of ten pounds to lift it. We measure distance in feet. According to our definition of work, the force must move the object through a distance. The amount of work done is therefore determined by how much force is used and how far the object is moved.

FIG. 266. Suppose that each bag weighs 100 pounds and has to be lifted to a height of 5 feet. How many foot-pounds of work will it take to lift each bag? (Ewing Galloway photo)

The unit to measure this is called the *foot-pound.* If a force of one pound is used to move an object through a distance of one foot, one foot-pound of work is done. Now you can measure how much work you do if you lift a stone weighing ten pounds to a height of three feet. You multiply the force (10 pounds) by the distance moved (3 feet), and you get 30 foot-pounds. To find out how much work is done, it is only necessary to multiply the force by the distance moved. If you weigh 100 pounds and you climb a stairs 10 feet high, how much work have you done?

You might think that the speed with which you move an object is a factor in determining how much work is done. This is not true. Whether a 200-pound man runs up a stairs to a height of 30 feet or walks up slowly makes no difference in the amount of work done. It may make him more tired to run up the stairs, but he accomplishes exactly the same amount of work in either case: He lifts 200 pounds to a height of 30 feet. The rate of doing work does not determine the amount of work done.

*Self-Testing Exercises.* 1. Two teams were having a tug of war. Both teams were pulling with all their strength. Neither team could move the other. According to the scientist's meaning of "work," were the members of the teams doing work? Explain your answer.

2. Make up a problem to show that you understand the meaning of the term "foot-pound."

3. Which would do more work: a man who lifted ten 100-pound sacks of flour three feet in five minutes, or a man who lifted 20 fifty-pound sacks of flour three feet in ten minutes? Why?

*Problems to Solve.* 1. Imagine that your friend is standing on a five-foot platform, trying to pull a fifty-pound box up to the platform with a rope. You get under the box and help by lifting it. When the box is four feet in the air, the rope breaks. You have to hold it where it is for two minutes until your friend can get down and help you lower it to the ground. How much work did you do during the two minutes?

2. A horse is pulling a wagon up a hill. Is the horse working? Finally the hill gets so steep that all the horse can do is keep the wagon from rolling down the hill. Is the horse working?

3. How could you find out how much work is done when a boat is pulled up on a beach for a distance of ten feet?

4. A bale of hay was lifted from a truck to a window seven feet above the truck. The hay weighed 85 lb. How much work was done?

5. How much work do you do in climbing a ladder until your feet are 15 feet above the ground?

DO MACHINES SAVE WORK? Now you are ready to see whether a machine does really save work; that is, whether you can get more work out of a machine than you put into it. You already know that it is easier to get into a wagon by walking up a plank than it is to lift yourself into the wagon. You can roll a heavy barrel up a plank into a truck when you cannot lift it. Does it really take less work to roll a barrel up a plank into a wagon?

*Experiment* 65. DOES IT REQUIRE LESS WORK TO ROLL AN OBJECT UP A PLANK THAN TO LIFT THE OBJECT THE SAME DISTANCE? Get a smooth board five feet long and one foot wide. Place one end of the board on a support so that it rests two feet above the top of a table. Get a small wagon with wheels that turn easily. Oil the wheels. Add some iron weights or some stones to the wagon to make the cart and the weights weigh about ten pounds.

Attach a spring balance to the loaded wagon and pull the wagon slowly up the plank at a uniform rate of speed. Have someone read the spring balance as you pull the load up the plank. How much force does it take to move the load? How much force does it take to lift the wagon and its contents? How does this compare with the force required to pull the load up the plank?

Fig. 267. In this picture the wagon and its contents weighed 10 pounds. The force required to pull the wagon was $4\frac{1}{4}$ pounds.

Now you can figure how much work was done in pulling the wagon up the plank. Let us suppose that it took a force of four pounds to pull the wagon up the five-foot plank. The work *put in* to the machine would be four pounds times five feet, or 20 foot-pounds. We will also suppose that the wagon and weights weighed ten pounds. It would be necessary to lift the wagon straight up for a distance of two feet to raise it the same height as it was when rolled up the plank. The work accomplished by the plank would therefore be ten pounds times two feet, or 20 foot-pounds. In other words, the work you put into the machine (rolling the wagon up the plank) is equal to the work the machine did (lifting the wagon two feet).

Now use this same method to measure the work put in and the work done by the machine in Figure 267. How much work was done in pulling the wagon up the plank? To find this, multiply the force needed by the length of the plank. (See Figure 268.) How much useful work was accomplished? To find this, multiply the weight of the wagon and its contents by the height to which they were lifted. When you compare the amount of work actually done in rolling the wagon up the plank with the amount of work required to lift the wagon, you find that you put more work into the machine than you actually got out of it. Why is this true? You remember that whenever two surfaces rub together, there is friction between them. In rolling the

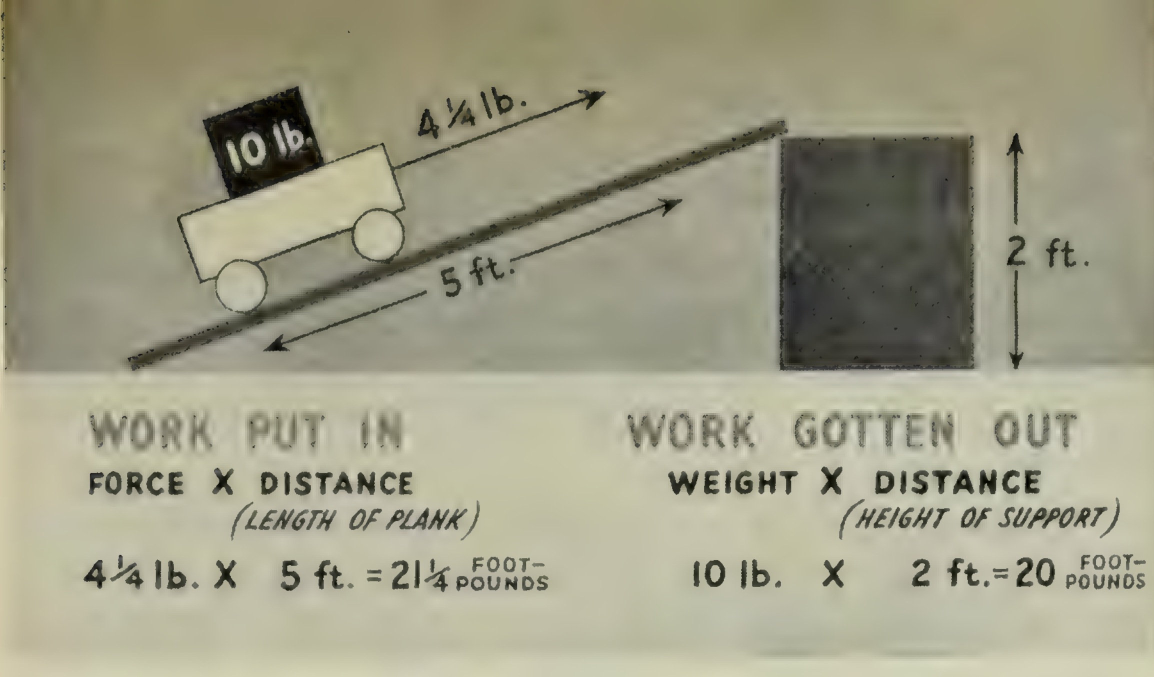


FIG. 268. This diagram will help you understand why an inclined plane helps do work but does not save work.

wagon up the plank you not only had to overcome the weight of the wagon, but you also had to overcome the friction between the moving parts of the wagon.

The answer to our question, Does a machine save work? is "No." There is always some friction in a machine; therefore more work is always put into a machine than is got from it. That is, you always do more work on the machine than the machine does for you. Perhaps you have heard people say that a certain machine is very efficient. What does this mean? It means that we get almost as much work out of the machine as is put into it. For example, suppose that 100 foot-pounds of work are put into a machine, and 90 foot-pounds of useful work are accomplished. The efficiency of such a machine is 90 per cent. To find the efficiency of a machine, it is only necessary to divide the *work got out* by the *work put in.*

You can now find the efficiency of the machine you used in Experiment 65. Take the amount of work accomplished by lifting the wagon through a distance of two feet. Divide it by the amount of work that was done in pulling the wagon up the plank. What do you find?

*Self-Testing Exercises.* 1. Answer the following questions regarding Experiment 65:

a) How much force was required to pull the wagon up the plank?
b) How much work was done?
c) How much force was required to lift the wagon?
d) How much useful work is done when the wagon is lifted up to the same height as it is rolled up?

e) Which is greater, the work in or the work out? Explain.

f) What is the efficiency of your machine?

2. A certain machine is 50% efficient. What does this mean?

3. In actual use do we ever get as much work out of a machine as we put into it? Explain.

*Problems to Solve.* 1. A barrel that weighs 200 pounds is lifted into a wagon three feet above the ground. How much work is done?

2. The same barrel is rolled up a plank ten feet long into the wagon. It is found that a force of 62 pounds is necessary. How much work was done in this case? What is the efficiency of this machine?

WHY ARE MACHINES ABLE TO EXERT SUCH LARGE FORCES? You are no doubt wondering, "If we have to put as much (or more) work into machines than we get from them, why should we use them at all?" This is a good question to ask. In answering it think of the experiment again. You found that you used a small force to lift a much heavier weight. For example, if the weight of the wagon was ten pounds, you found that you could pull it up the board with a force of four pounds. However (and this is the important point to see), you had to move the small force through a greater distance (5 feet) than if you had lifted the weight to the upper end of the plank (2 feet). In other words, to increase your force two and one-half times (10 divided by 4), you had to move the force through two and one-half times the distance the weight moved (5 divided by 2).

The advantage of using such a machine is that it is easier to move a small force through a greater distance than it is to move a large force through a shorter distance. For example, you could not lift a 200-pound barrel from the ground into a truck three feet from the ground. However, you might be able to roll the barrel up a ten-foot plank into the truck, because you would apply a much smaller force through a greater distance.

Perhaps you now understand how a small force can be used to lift a large weight: The small force must move through a longer distance. Also, you understand why machines do not "save work." The work we put into a machine equals the work we get from it (neglecting friction). We use machines because they make work easier.

There is a way of calculating how much help we can get from a machine. We call the amount of help we get from a machine its *mechanical advantage*. Now let us figure out the mechanical advantage of the board you used in Experiment 65. You found that you could lift a 10-pound weight with a force of about 4 pounds. The mechanical advantage of this machine was 2½ (10 divided by 4). So, one way of finding mechanical advantage is to divide the weight lifted by the force needed to lift it.

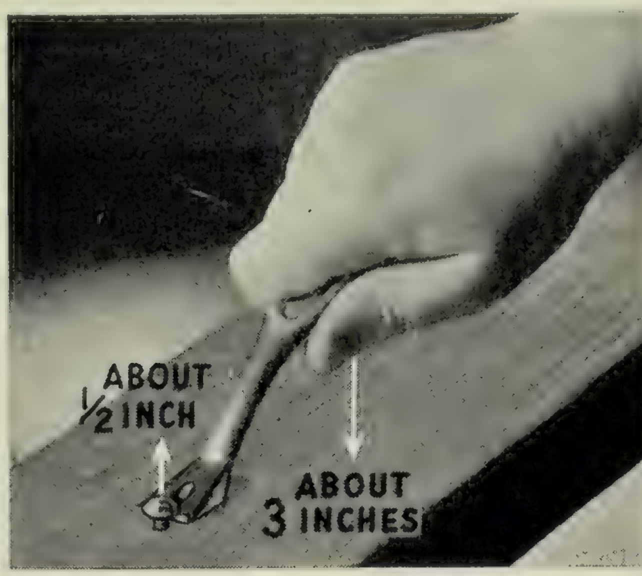

Fig. 269. Explain what this picture shows about this kind of machine.

Suppose you wanted to lift the 10-pound weight in Experiment 65 with a force smaller than 4 pounds. How could you do it? You could use a longer board, for example, a board 10 feet long. This time the force would move 10 feet to lift the weight 2 feet. The mechanical advantage in this case would be 5 (10 divided by 2). In this example you used another method of finding mechanical advantage. You divided the distance the force moved by the distance the weight moved.

What would be the mechanical advantage of a machine in which the force moved ten feet and the weight moved one foot? You can easily see that the answer is ten. Here is an important point to remember: In any machine the greater the distance the force moves as compared with the distance the weight moves, the greater the mechanical advantage. You are now ready to find how other simple machines operate and why they are helpful.

*Self-Testing Exercises.* 1. If more work is put into a machine than we get from it, why do we use a machine?

2. What does "mechanical advantage" mean?

3. If a machine can lift a weight of 100 pounds with a force of 10 pounds, what is the mechanical advantage of the machine?

4. Why can small forces lift large weights when a machine is used?

*Problems to Solve.* 1. Suppose you have a barrel weighing 200 pounds which you want to lift three feet into a wagon. With your muscles you can only exert a force of 50 pounds. How long a plank would you use?

2. If you used a plank 12 feet long to roll a barrel up into a wagon bed three feet high, what would be the mechanical advantage? If the barrel weighed 100 pounds, how much force would you need to exert?

## ¶ 3. What are the kinds of simple machines?

HOW DO LEVERS HELP US? Now that you understand what machines can do, you are ready to study the different kinds of simple machines. Scientists have classified all simple machines into six groups, as follows: the *inclined plane*, the *lever*, the *screw*, the *wheel and axle*, the *pulley*, and the *wedge*. When you use a pole, a plank, or a crowbar to pry up a heavy stone, you are using a lever.

*Experiment* 66. HOW DO LEVERS WORK? (*a*) Fasten the ring of a spring scale to the end of a strong, straight stick. The stick should be more than three feet long. Balance the stick and spring scale on a support about a foot above the table. Hang a five-pound weight on the opposite end of the stick. Have the distance from the support to the weight equal to the distance from the spring scale to the support. Have two classmates each hold yardsticks vertically just back of each end of the balanced yardstick, but be sure they do not touch it.

Now pull downward on the hook of the spring scale until the stick touches the top of the table. (Let your hand and the scale move down past the edge of the table to do this.) How much force did it take to move the weight upward? How far did the weight move upward? How far did your hand move downward?

*b*) Now move the weight toward the support to make it only one-third as far away as the spring scale (Figure 270). Pull down on the scale until the yardstick touches the top of the table. How much force did you use? How far did the weight move upward? How far did your hand move downward?

The place where a lever is rested or supported is called the *fulcrum*. The distance from the weight to the fulcrum is the *weight-arm*, and the distance from the force (your hand) to the

FIG. 270. Apparatus for the second part of Experiment 66

fulcrum is the *force-arm*. In part *a* of the experiment you found that the force needed to lift the weight was about equal to the weight. In this case, the length of the force-arm was equal to the length of the weight-arm. When the force-arm and the weight-arm are equal in length, both arms move the same distance to lift the weight. Therefore, the distance the force moves is equal to the distance the weight moves, and the mechanical advantage of the lever is *one*.

In part *b* of the experiment the force-arm was longer than the weight-arm. The force moved through a much greater distance than the weight, and, as you found, a smaller force could lift the weight. So, if you wish to increase the mechanical advantage of this kind of machine, you must make the force-arm as long as possible in comparison with the weight-arm. Then a small force can be moved through a greater distance to lift a large weight a smaller distance. For example, if you wish to pry up a heavy weight with a crowbar, keep the fulcrum as close to the weight as possible. Such levers make work easier because you use a small force to move a much greater weight. But remember that you do not save work, because you move the small force through a greater distance.

Suppose you wanted to pull a post out of the ground with a lever. You could not place one end of the lever under the post, as you did with the stone. You would have to fasten the post to the lever, as the man in Figure 271 has done. Then you would rest the short end of the lever on a block and lift upward at the

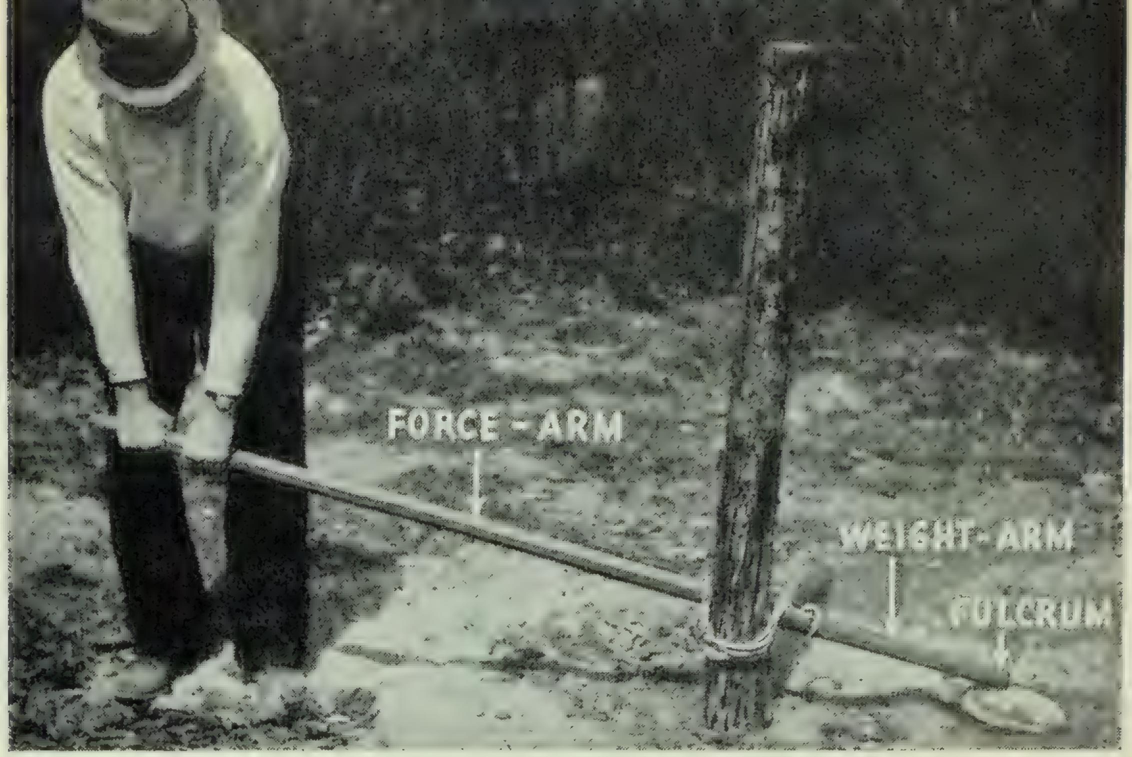


FIG. 271. In this home-made post-puller the lever is fastened to the post with rope. As the post is pulled higher, the rope can always be slipped down to get a new hold on the post. (Claude J. Dyer photo)

other end. You would have to pull upward through a long distance to move the post a short distance. Notice that the fulcrum is the point on the lever that does not move. The lever turns about the fulcrum. The fulcrum may be at the end of the lever or anywhere between the weight and the force. No matter where the fulcrum is, a lever multiplies force when the force-arm is longer than the weight-arm. Pliers, nut-crackers, tack-pullers, and pump handles are levers that multiply force.

However, not all levers are used to multiply force. When the weight-arm is longer than the force-arm, we multiply distance and speed instead of force. In the fishing pole the fulcrum is at the end of the pole toward your body. You apply the force with the hand that is only a short distance away from the fulcrum. The fish attached to the end of the pole is the weight. It moves farther and faster than your hand. The crane on page 379, fire tongs, a ball bat, a pitchfork, and a broom or mop are all examples of levers that multiply distance and speed.

Notice that when the fulcrum of a lever is between the force and the weight, one end goes up and the other goes down, thus changing the direction of motion. Figure 263 on page 382 shows a lever that is changing the direction of motion as well as increasing the force.

*Self-Testing Exercises.* 1. Make a drawing to show how you could pry up a stone weighing 200 pounds by using a force of 40 pounds.

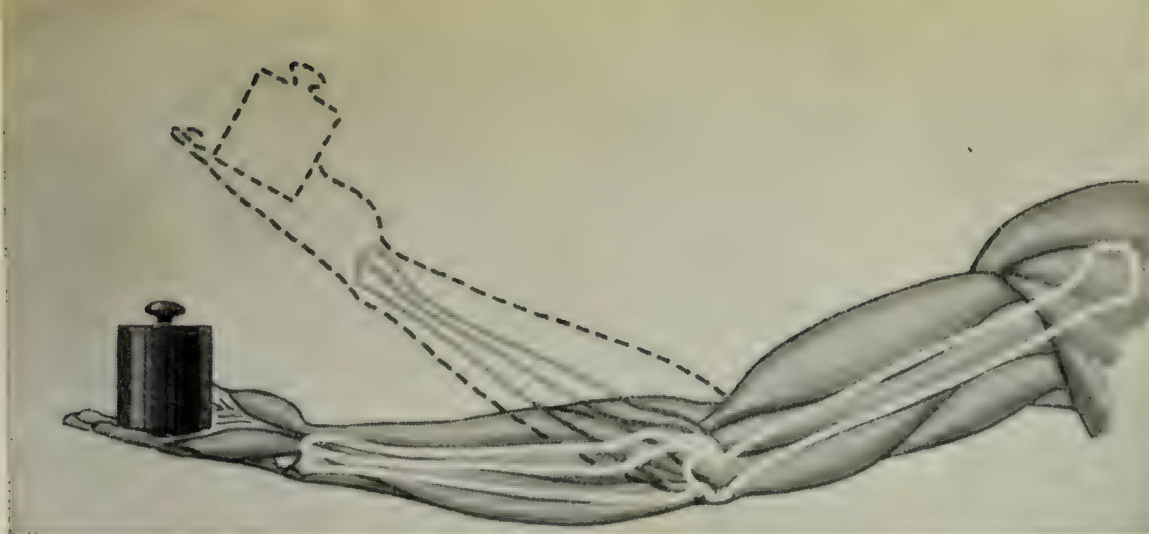

FIG. 272. Can you tell what kind of advantage the bone lever in your forearm gives?

What is the mechanical advantage of your lever? How does the mechanical advantage of your lever compare with the lengths of the force-arm and the weight-arm?

2. Explain why it is possible to lift a heavy weight with a small force by using a lever.

3. Make sketches to show the different ways in which the fulcrum, weight-arm, and force-arm may be arranged. Which ways multiply force? Which multiply speed and distance?

*Problems to Solve.* 1. Keep a record of all the levers you can discover for yourself. After each one tell whether it is used to gain an advantage of force or of distance or to change the direction of force.

2. Suppose you were carrying a heavy bag on a stick over your shoulder. Would you keep the bag close to your shoulder or out near the end of the stick? Make a drawing and explain why.

3. Press down a key of a typewriter. What kind of machine is it? Make a drawing that will show whether you get an advantage of distance or of force.

4. Shears for cutting tin and metal have long handles and short blades. Shears for cutting paper have short handles and long blades. Explain why they are not constructed alike.

HOW DO PULLEYS HELP US? When you open a window that has cords attached to it, you are using another kind of simple machine. The cords run over small grooved wheels, called *pulleys,* in the window frame. Did you ever see a farmer lift a load of hay into a barn by using a rope and pulleys? Perhaps you have used a pulley and have found that it made your work easier to do. There are two different ways of using pulleys to do work. Experiment 67 on the next page will help you understand both of these ways.

FIG. 273. Single fixed pulley

FIG. 274. A single movable pulley

FIG. 275. Block and tackle

*Experiment* 67. HOW DO PULLEYS WORK? (*a*) Fasten a single pulley three feet above the top of a table, as Figure 273 shows. Attach a strong cord to a pail of sand that weighs five pounds. Run the cord over the rim of the pulley wheel. Fasten the other end of the cord to the hook of the spring scale. Stand a yardstick on end behind the pulley so that you can tell how far the weight moves as your hand pulls down on the cord.

Hold the ring of the spring scale in one hand and pull downward at a uniform rate until your hand has moved one foot. How far has the weight moved? In what direction has it moved? How much force was registered on the spring scale in moving the five-pound weight a distance of one foot? What advantage is given by the pulley arranged in this way?

*b*) Rig up a pulley like the one in Figure 274. This time the pail of sand and the pulley together should weigh five pounds. Attach the weight to the pulley and lift upward on the ring of the spring scale. Move your hand upward at a uniform rate for a distance of two feet. How far has the weight moved? How much force was registered on the spring scale? How does this compare with the weight of the pail of sand?

*c*) Rig up a combination of pulleys, as in Figure 275. Use a pail of sand that weighs eight pounds. Hold the spring scale in your hand and move your hand downward at a uniform rate for two feet. In what direction did the weight move? How far? What did the reading on the spring scale show? How did this compare with the weight of the pail of sand?

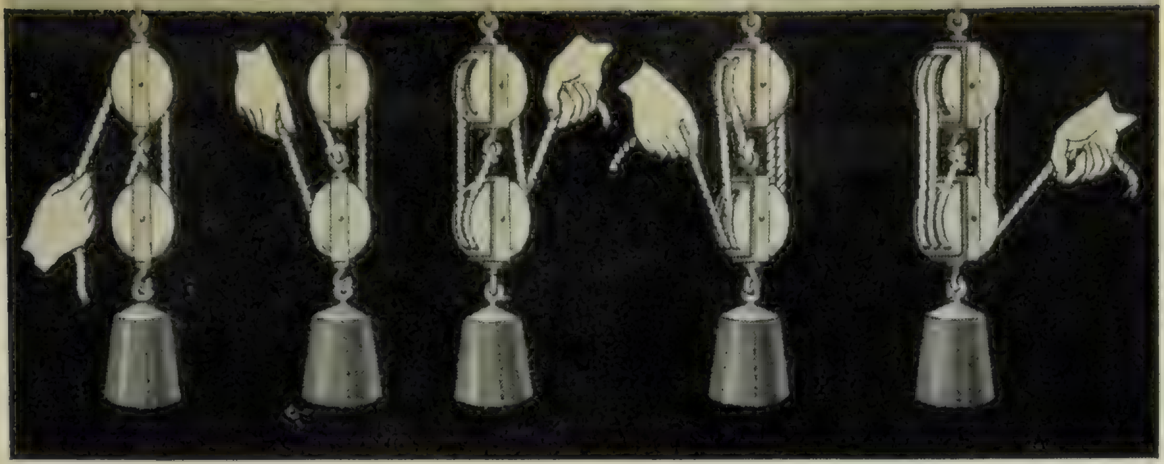

Fig. 276. This picture shows various ways in which pulleys may be combined to make work easier.

In part *a* of the experiment you found that when you lifted the weight a distance of one foot, you had to move the force a distance of one foot. Also, the force that was needed to lift the weight was about equal to the weight. As in the case of the lever (part *a* of Experiment 66), the mechanical advantage of this kind of machine is *one* when we pay no attention to friction in the moving parts. A pulley arranged like this one in Figure 273 is known as a *fixed pulley*. It is called a fixed pulley because it does not move up or down.

Probably it does not seem to be of much help if you have to put as much work in as you get out. But a fixed pulley is of decided help in one way. Did you ever use a pulley of this kind to pull a flag to the top of a flag pole? It did not take much force to get the flag to the top of its very tall pole, but suppose the pulley had not been there. You would have had to climb to the top of the pole carrying the weight of your body and the flag with you. So the real advantage in using a fixed pulley is that it changes the direction of the force you use. This makes it convenient for you to get the flag in its proper place.

In part *b* of Experiment 67 you used another arrangement of a machine: a *movable pulley*. As you pulled upward on the cord, the pulley moved upward with the weight, and your hand moved twice as far as the weight; so you lifted a five-pound weight with a force of two and one-half pounds. The mechanical advantage of a single movable pulley is *two* (when we pay no attention to friction).

A combination of pulleys and a rope, known as a *block and tackle*, is most often used by workmen. In part c of Experiment 67 you found that with a block-and-tackle arrangement you could lift an eight-pound weight by using only about two pounds

Fig. 277. With this machine the force moves in a circle to pull the pail in a straight line.

of force (shown on spring balance). The force moved four times as far as the weight moved; so the mechanical advantage was *four*.

Of course, there are many other ways in which combinations of pulleys can be rigged up (Figure 276). But the important thing to remember is this: The greater the number of pulleys used, the greater the mechanical advantage. This is true because the greater the number of pulleys, the farther the force must move to lift the weight a certain distance. When you see painters raising scaffolds or workmen lifting a piano with a block and tackle, you will understand how pulleys make work easier.

*Self-Testing Exercises.* 1. Give an example of your own in which you have seen a single fixed pulley used. If you have not seen one, try to make up a situation in which you might use one.

2. Make a drawing that will show how you might use a block and tackle to lift a boat weighing 300 pounds out of the water. Assume that you can pull with a force of 60 pounds. If you lifted the boat four feet, how far would you have to pull the rope? What would be the mechanical advantage?

How do inclined planes help us? The plank you used in Experiment 65 was an *inclined plane*. You found that it took less force to roll a loaded cart up a plank than to lift the cart. You also learned why this was true. The distance the barrel is moved up the plank is much greater than the vertical distance the barrel is raised. It is easy to find what the mechanical advantage of an inclined plane is. All that is necessary is to divide the length of the plane by the height of the upper end. In other words, if a plane is 10 feet long and the distance the object is raised is two feet, the mechanical advantage is *five* (if we neglect friction). The longer the board used, therefore, the greater the mechanical advantage.

HOW DOES A WHEEL AND AXLE HELP US? Have you ever seen a device like the one in Figure 277 used to raise water from a well or to raise a ship's anchor or some other heavy weight? This kind of simple machine is a *wheel and axle*. An experiment will help you understand how wheel-and-axle machines make work easier.

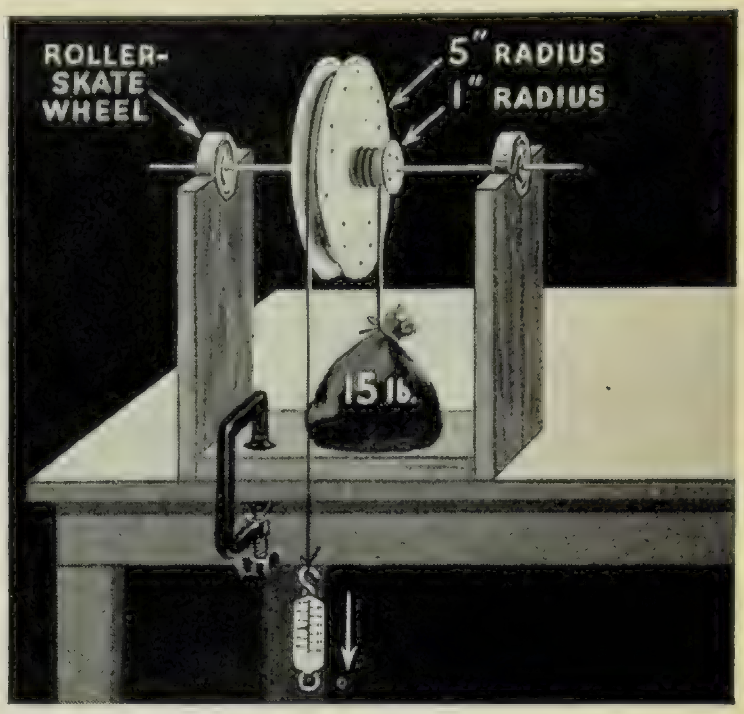

FIG. 278. Apparatus for Experiment 68

*Experiment* 68. HOW DOES A WHEEL AND AXLE MAKE WORK EASIER? In your school workshop or at home, make a piece of apparatus like the one in Figure 278. Oil the bearings. Fasten a fifteen-pound bag of sand to a small nail driven into the axle. Adjust the apparatus so that when you pull down on the heavy cord attached to the rim of the wheel, the cord will roll around the axle and lift the weight. Be sure to clamp the apparatus to the table.

When the apparatus is adjusted, pull down on the spring balance at a uniform rate of speed. What is the reading on the spring balance? Have two of your classmates hold yardsticks behind the weight and behind your hand. How far is the weight lifted? How far does your hand move?

In the experiment you found that it took only a little more than three pounds of force to lift the fifteen-pound weight. As the movable part of the machine turned, the force had to travel a distance that was equal to the circumference of the large wheel. At the same time, the weight had to travel a distance that was equal to the circumference of the axle. From the measurements you made in the experiment, you found that the force moved five times as far as the weight moved. Thus, the mechanical advantage of your wheel-and-axle machine was *five*.

How could you increase the mechanical advantage of a wheel and axle? As in the case of the other machines you have studied, this could be done by making the force move a greater distance in comparison with the distance the weight moves. Remember

that the force has to move a distance as great as the circumference of the wheel while the weight is moving a distance equal to the circumference of the axle. With a larger wheel and a smaller axle the force would have to move through a greater distance while the weight moved a smaller distance. In this way the wheel and axle would help make work even easier.

In Problem 1 you found several examples of the wheel and axle. Some other machines of this kind are hoisting derricks on automobile wreckers, cranks, and the works of clocks and watches. (A crank acts as one spoke of the wheel of a wheel and axle.) When you study power machines in Unit 15, you will discover that almost every one of them is, in part, a wheel-and-axle machine.

*Self-Testing Exercises.* 1. How could you increase the mechanical advantage of a wheel-and-axle machine?

2. Why does a car steer more easily if the steering-wheel has a large diameter?

HOW DO SCREWS HELP US DO WORK? You could not possibly lift one end of an automobile with the unaided strength of your arms, legs, and back. But you probably have lifted part of the weight of an automobile with the help of a *jack* (Figure 279). You may have seen workmen lift the corner of a house with a large *jack-screw*. How can these small machines lift such heavy objects by the use of only small amounts of force?

In each of these devices a screw helps do work. A screw is really nothing but a cylinder with a spiral ridge around it. The spiral ridge is the *thread*. Some threads are V-shaped, and others are rectangular. Examine several kinds of screws to see what the threads are like. A screw is a kind of inclined plane, as you can see from this experiment: Cut a right-angle triangle from lightweight cardboard. Begin at the broad end and wrap it around a pencil. You will have a model of a screw. The screw in a jack-screw fits into a threaded base. The base is heavy and does not move. A long bar or handle is put into an opening in the top of the threaded cylinder. While the end of the handle is being pushed or pulled around in a large circle, the cylinder makes a smaller turn. This raises the cylinder a height equal to the dis-

FIG. 279. In this picture of an automobile jack can you find a wheel and axle in the jack? Is any part of the handle a wheel and axle?

tance between the top of one thread and the top of the next one This distance is known as the *pitch*.

With screws, as with other simple machines, the mechanical advantage is in having the force move a great distance while the weight is lifted a very small distance. The force moves around the circumference of the big circle made by the handle, while the weight is lifted only the small distance of the pitch of the screw. You can easily see that the mechanical advantage of this machine is large, for the circumference of the circle made by the handle will be many times greater than the pitch of the screw. How could you increase the mechanical advantage of a jack-screw? One way would be to use a longer handle. Then the force would move through a much greater distance in comparison with the distance the weight was lifted. Another way would be to use a screw having a smaller pitch.

You may have seen a meat-grinder, a bookbinder's press, a vise, and other similar machines in use. Each of these machines has a screw for its principal working part. Now when you see such machines being used, you will know why they are of so much help in doing work.

*Self-Testing Exercises.* 1. Which would make a jack-screw easier to operate: (*a*) a handle three feet long or (*b*) a handle two feet long? Explain your answer.

2. Why is it possible to have such a high mechanical advantage with a jack-screw?

3. What is the "pitch" of a screw?

FIG. 280. You can easily see that a snow plow like this is a wedge and that it is made of two inclined planes.

*Problems to Solve.* 1. Explain why you can screw a nut on a bolt very much tighter with a wrench than you can with your fingers.

2. Make a drawing of a vise. Why is it possible to clamp objects so tightly in a vise?

HOW DO WEDGES HELP US DO WORK? Suppose you needed to move a weight so great that you could not roll it up an inclined plane. Instead of trying to pull or roll the weight, you could drive the inclined plane under it. An inclined plane used in this way is called a *wedge*. When a woodsman uses an axe to split wood and a farmer uses a plow to break the soil, they are using wedges. The blades of carpenter's planes, knife blades, and chisels are other examples of wedges.

When a woodsman splits a block of wood with a wedge, he must force the wedge in a long distance to separate the wood a little. For example, if the wedge is ten inches long and two inches thick at the top, the wedge has to move ten inches to move the pieces of the block two inches apart. In other words, the force moves five times as far as the parts of the block spread, and the mechanical advantage of this machine is *five*.

What kind of wedge would you use to get greater mechanical advantage? If you used a wedge twelve inches long and two inches thick at the top, the force would move twelve inches while the wood was being forced two inches apart. The mechanical advantage of this wedge would be six. The longer the slope of the wedge and the narrower it is at the top, the greater its mechanical advantage will be. However, you must remember that the friction between the sides of the wedge and the material that is being split reduces the advantage. This is especially true because usually the material squeezes tightly against the wedge.

*Self-Testing Exercises.* 1. A wedge is a very inefficient machine. Explain why.

2. If you want to use a wedge that has a very large mechanical advantage, what kind of wedge should you use?

*Problems to Solve.* 1. Measure the screw of an automobile jack to find its pitch. Would a wider pitch between the threads of the screw make the jack easier or harder to operate? Explain.

2. Suppose you can pull with a force of 100 pounds. How heavy a load could you lift with a single movable pulley? With a single fixed pulley? Why?

3. In a wheel and axle the wheel has a circumference of three feet, and the axle has a circumference of six inches. What is the mechanical advantage of the machine? If you could pull with a force of 100 pounds, how heavy a weight could you lift with this machine?

4. A jack-screw has a pitch of one-fourth inch. The handle is three feet long. If the screw is well oiled, about how much could you lift by exerting a force of 50 pounds on the end of the handle?

HOW DO SIMPLE MACHINES WORK TOGETHER IN COMPLEX MACHINES? Many of the machines you use are combinations of simple machines. Take for example the bicycle. As you ride, you push down on the pedals. The pedals and the front sprocket make a wheel and axle. The pedals are pieces of metal that act like spokes of the wheel, and the sprocket is the "axle." The force from the sprocket is transmitted to the rear sprocket by a chain. The rear sprocket and the rear wheel form a second wheel and axle. But in this case the force is applied at the axle, and the resistance is at the rim of the wheel. Thus this wheel and axle at the rear multiplies distance. With a large sprocket driving a small one and the small one turning a wheel with a large circumference, this combination of simple machines produces a great increase of speed and distance between your foot and the ground.

The common food-grinder is another combination of simple machines. The crank is one spoke of the wheel of a wheel and axle. On the axle is a screw. Food is caught in this screw and pushed forward against the cutting edges at the outer end. These cutting edges are wedges. Thus the food-grinder is a combination of a wheel and axle, a screw, and wedges. Several additional

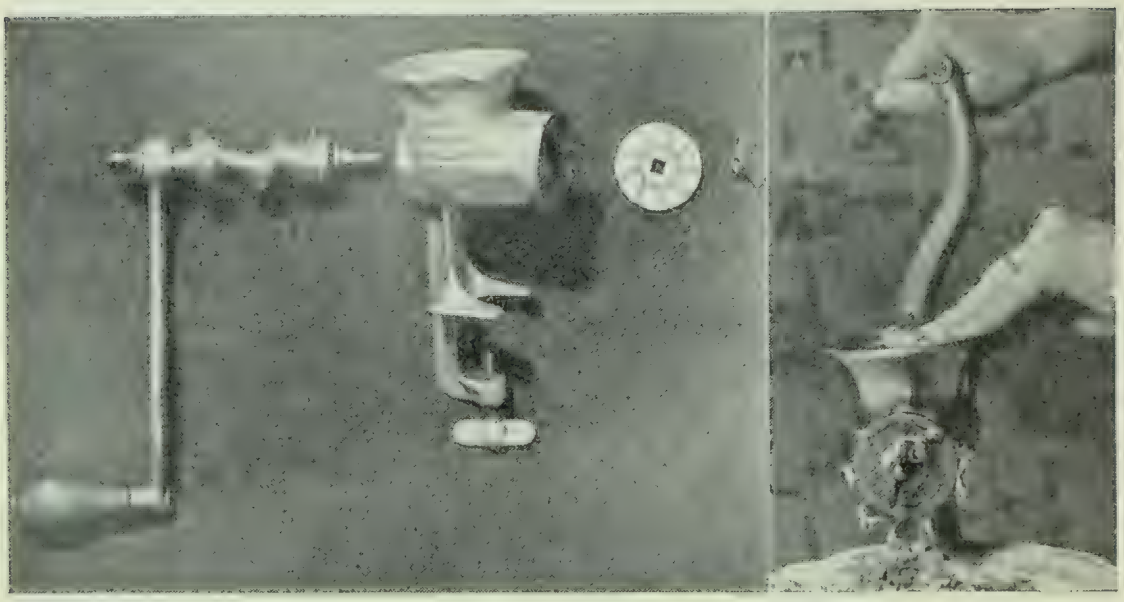

FIG. 281. A food-grinder with its screw, wedges, and wheel and axle

screws are used to fasten the machine together and to clamp it to a table.

If you have at home a sewing-machine that you operate by pressing on a treadle, you will find that it is a combination of many simple machines (Figure 282). You apply force to the treadle, which is a lever. A rod transmits the force to a crank that is part of a wheel and axle. By means of a belt, the large wheel drives a small wheel at high speed to operate the parts of the sewing-machine. These parts consist of many wheels and axles and levers. The needle that does the sewing is a wedge. All of these simple machines operating together increase the speed of the machine and change the direction of your force.

An easy way to find the mechanical advantage of a complicated machine that multiplies force is to use the general principle for simple machines. Move the part where the force is applied a distance of, perhaps, three feet. Then measure the distance the working part has moved. Divide the first distance by the second to get the mechanical advantage. Thus, if the force has moved three feet and the working part has moved one-half inch, the mechanical advantage is 72 (36 inches divided by .5 inch).

*Self-Testing Exercises.* 1. What is the advantage of using a combination of simple machines?

2. How can you find the mechanical advantage of a complicated machine?

*Problems to Solve.* 1. Suppose that the front sprocket wheel of a bicycle is eight inches in diameter, and the rear sprocket wheel is two inches in diameter. Suppose, also, that the rear wheel is twenty-eight inches in diameter. How far does the bicycle go while the pedal makes one complete revolution? (You might figure this out, using the dimensions on your own bicycle.)

2. Find out what is meant by a "high-gear bicycle" and a "low-gear bicycle."

3. Suppose that you live in a place where it is rather hilly. The dealer shows you two bicycles. On one bicycle the back wheel goes around five times while the pedals go around once. On the other, the back wheel goes around three and one-half times while the pedals go around once. Which bicycle would you rather have? Why?

4. Examine as many of the following machines as you can to find what kind of simple machine is the basis of operation of each: clothes-wringer, washing-machine, broom, ice-cream freezer, grindstone, sugar tongs, shovel, can-opener, door-knob, key. Examine other machines that are not mentioned in this list. You may find that some of the complicated machines are made of several kinds of simple machines.

5. Find out how the brakes on an automobile work. (If possible, use the handbook of instructions that ordinarily comes with the car.) Figure out, if you can, the mechanical advantage of the brake mechanism.

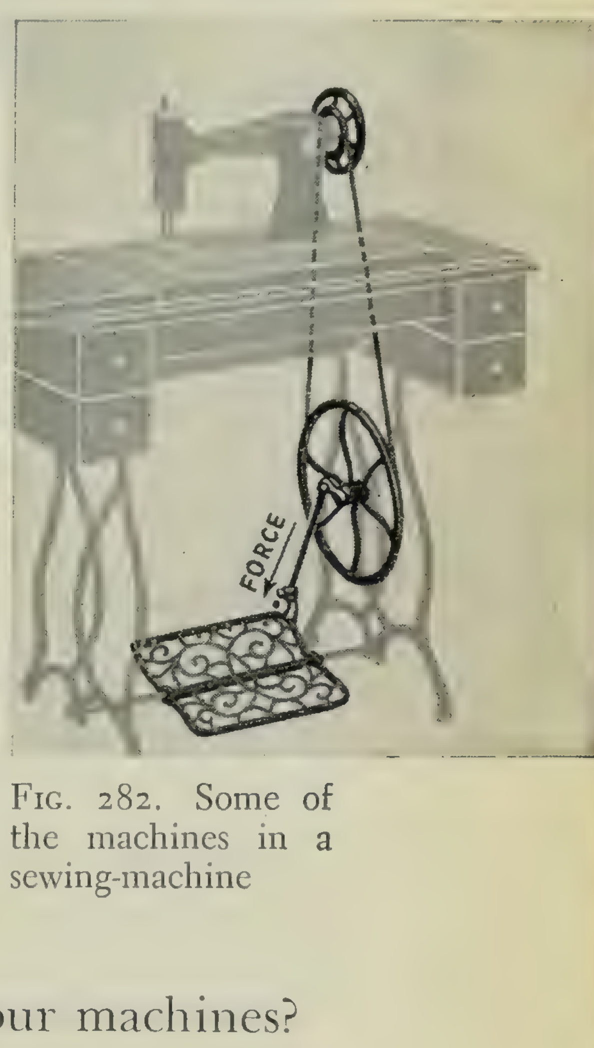


FIG. 282. Some of the machines in a sewing-machine

## 4. How do we control friction in our machines?

HOW CAN FRICTION BE REDUCED? In Problem 2 you learned that a machine can never give out 100 per cent of the work that is put into it. You learned also that the work which is lost in a machine is lost because of friction between its moving parts. Therefore you can see that it is important to have machines work with as little friction as possible if we are to get the most work out of them for the energy that it takes to run them. A simple

FIG. 283. You can see the ball bearings in these wheels.

FIG. 284. The rollers of a large roller bearing (Starek Studios)

experiment will help you realize how much the friction in a machine can be reduced.

*Experiment* 69. HOW MUCH DO ROLLERS REDUCE FRICTION? (*a*) Get a chalk box or a cigar box and some metal or wooden rollers. Round pencils will do very well. Put weights or sand in your box until it weighs several pounds. Fasten a spring balance to one end of the box and slide it along the top of a table at a uniform rate of speed. How much force is needed to pull the box?

*b*) Now put rollers under the box and pull the load along the top of the table at a uniform rate of speed. How much force is needed to pull the box when it is on rollers?

In the experiment you have just done, you found that it took much more force to slide the box along the table-top than it did to move the load on rollers. In any machine there are always moving parts that are in contact with each other. These parts can never be perfectly smooth. The little ridges and depressions on one part move against uneven places in the other part and cause friction. When surfaces slide past each other in this way, there is *sliding friction* between them. The bottom of the chalk box resting on the table-top caused sliding friction that had to be overcome before you could move the load. In part *b* of the experiment you put rollers between the surfaces. As the box and the rollers moved along, the tiny ridges and depressions that

cause friction were lifted out of each other instead of being pulled against each other. Thus it was very much easier for the box to move along.

But there was still some friction. This friction between a roller or a wheel and a surface is called *rolling friction*. It is usually much less than sliding friction. Examine a roller-skate wheel carefully to see how it is made. Small steel balls roll around the skate axles. These sets of steel balls are known as *ball bearings* (Figure 283). In many kinds of machines, such as automobiles and bicycles, they substitute rolling friction for sliding friction between the wheels and the axles.

Figure 284 shows a kind of bearing that is used in heavier machinery. It looks like a set of tiny rollers in a larger wheel, and that is just what it is. It is a *roller bearing*. The axle of a heavy piece of machinery rests inside the rollers. As the axle turns, it turns the rollers around inside the bearing. Thus the rollers make the friction much less. Roller bearings, used on the axles of the best trains today, make it possible for the locomotives to pull heavier loads and increase our comfort as we ride. So one way of reducing friction is to use steel balls or rollers instead of allowing surfaces to rub against each other.

We can reduce friction in another way. Rub two pieces of very rough wood against each other and notice how hard they are to move. Sandpaper each piece of wood until it is as smooth as you can get it. Rub the pieces together again, and you will find that they are much easier to move. Do you see that another way of reducing friction between moving surfaces is to make the surfaces as smooth as possible?

Take the back off a good watch and find the place where the axles of the wheels turn. Be careful not to touch the works or to get any dust inside. Jewellers have learned that they can make watches keep better time if they reduce friction between the moving parts. Therefore the ends of each main axle are set in hard minerals known as *jewels*. These hard substances are made very smooth, of course, so that the delicate mainspring can turn the wheels easily. Can you see why *jewelled bearings* make a watch more expensive? The next time you hear someone say that he has a twenty-one-jewel watch, you will know what he means.

FIG. 285. There are at least four jewelled watch bearings that can be seen in this picture. What simple machines can you see? (Starek Studios)

There is still another kind of bearing used where parts of machines rub against each other. If the axles of a machine and the bearings into which they fit were made of the same kind of metal, the machine would not run very easily. The tiny ridges and depressions in the axle would fit into the ridges and depressions in the bearings, and much friction would be produced. To reduce friction and wear where ball or roller bearings cannot be used, steel axles turn in bearings that are lined with a kind of soft metal known as *Babbitt metal.*

Did you ever ride in an automobile that squeaked? The squeaking noise grew very tiresome, and either you or your father probably said, "This car should be greased." When we grease or oil parts of machines that rub against other parts, a thin film of oil spreads out over the parts and keeps them from actually touching each other. The oil lets one part slide over the other more easily, and friction is reduced. So a fourth way of reducing friction is by using oil or grease to keep the movable parts of a machine separated.

Of course, the proper kinds of oil must be selected for different purposes. The crank-case of a car needs *cylinder oil,* the gears need a pasty kind of grease, and the springs need an oil and *graphite* mixture. Graphite is a form of carbon that is very "slick." Small machines need a thin, light oil, commonly known as *machine oil,* and different kinds of oil are even used in automobiles in different kinds of weather.

HOW IS FRICTION USEFUL TO US? Can you imagine a world without friction? Probably the nearest to that kind of world occurs during an ice-storm. Roadways, walks, and steps are covered with a thick coating of the smoothest ice. The first

people out do not realize how little friction there is. They go down one after another. Many bones are broken, and almost everyone who goes out falls sooner or later. Anyone who tries to run can hardly get started. Autos turning corners go whirling round and round. When they get on the side of a sloping street or road, they cannot get back to the middle again. A person can hardly get up a slope on foot unless he has spiked soles, and automobiles need tire chains to press against the ice and increase the friction.

The strange and often dangerous things that happen when everything is coated with ice are caused by gravity and inertia acting with little friction. With no friction at all, gravity would pull all loose things down slopes into the low places. If you got started moving on a level space, you could not stop until you bumped squarely into something. Then you would probably bounce off and start sliding in another direction. If you were stopped, you could get started only by pushing against some other object. Of course, we shall never see a world without friction. The only frictionless place we know about is out in space where the earth and other heavenly bodies have been spinning ever since they were started. In empty space there is no friction to stop them. But here on earth we both have and want friction. In fact, we often go to a great deal of trouble to increase the friction between two surfaces.

When you strike a match, you choose a place that is rough, so that there will be greater friction. You have seen a speeding automobile come unexpectedly to a red light. The driver put on the brakes, and the machine soon came to a stop. The brakes are lined with a tough substance that causes much friction when pressed tightly against the *brake drums* on the wheels. The surfaces of the *brake linings* hold back on the surfaces of the drums and thus stop the wheels. At the same time the rubber tires with their ridges and grooves (the *tread*) "grip" the road with much friction and do their part in stopping the car.

You can now understand that there are many places where friction in our machines must be controlled. Friction always changes mechanical energy into heat energy. This energy is lost. In the bearings and other rubbing surfaces of machines we are

FIG. 286. On slick gymnasium floors we wear rubber-soled shoes, usually with ridges on the soles, to increase the friction between the floor and the shoes. (Starek Studios)

careful to have as little friction as possible. Thus our work is done with less wasted energy, and the surfaces are kept cool and do not wear out rapidly. But brakes, tires, and other parts must have as much friction as possible. Thus, even though they change motion into heat, they can stop our machines when that is necessary.

All important machines are carefully inspected before use to make sure that the friction-controlling devices are in order. Mechanics go carefully over each locomotive, aeroplane engine, and racing-car. They put oil on bearings, and they see that there is fresh oil in all the reservoirs, with no leaks in the oil pipes. They inspect the bearings to see that there are no worn or loose-fitting Babbitt metal linings and no broken rollers or balls where rolling friction is used. The brake linings must be in good condition and correctly adjusted. The sand-box of the locomotive must be full so that the engineer can "sand the track" for quick stops. The tires of automobiles must have good treads.

If we are wise, we will check our own machines just as carefully, or see that they are inspected by experts. Then they will do their work well and last longer. In the case of our automobiles, we ourselves may live much longer because we are able to use friction effectively when we need it.

*Self-Testing Exercises.* 1. Make a list of ways in which friction helps. In what ways is it a disadvantage?

2. How can we reduce friction? If possible, give examples different from those used in the text to illustrate your explanations.

3. Why do we often substitute rolling friction for sliding friction? Give a reason for the difference.

*Problems to Solve.* 1. Why are different kinds of oils used in different kinds of machines? Talk with "oil men" and read manuals that tell how to take care of machines.

2. What is the *coefficient of friction?* A physics book will probably give you the answer. Can you calculate the coefficients of friction in parts *a* and *b* of Experiment 69?

## Looking Back at Unit 12

1. Copy the heading of each sub-problem of this unit. Try to answer each of these questions as briefly as possible and in your own words. The first sub-problem is on page 384: *How is work measured?*

2. Show that you understand the meaning of these words:

| | | |
|---|---|---|
| *mechanical advantage* | *fulcrum* | *work* |
| *block and tackle* | *machine* | *jewel (watch)* |
| *pitch (of a screw)* | *foot-pound* | *roller-bearing* |
| *lever* | *jack-screw* | *wheel and axle* |
| *wedge* | *friction* | *screw* |

## Additional Exercises

1. Get the members of your class to bring to school many different kinds of simple machines. Prepare an exhibit of these machines. Put a label on each machine, telling its class, how it works, its mechanical advantage (if possible), and other important items you may wish to add.

2. See how many simple machines you can find in a kitchen. Make a list of levers, wedges, etc., that you find.

3. Try to rig up a block-and-tackle system of pulleys that has six supporting cords. Make a diagram if you cannot get the pulleys. What is the mechanical advantage of your system?

4. How would the amount of work done in carrying a fifty-pound box ten feet along a level floor compare with the amount of work done in carrying the same box up a ten-foot stairway?

5. Suppose a 160-pound man is painting the side of a house. He sits on a plank supported by a set of pulleys at either end. The plank weighs 25 pounds. How much work does he do if he pulls on the rope supporting the pulleys and raises himself and the plank 25 feet?

6. Visit an automobile repair shop or machine shop to learn what use is made of simple machines. In a repair shop you can see many of the inner parts of automobiles. Be sure to get permission to look around the shop. Be careful not to get in the way of the mechanics, and do not handle things that should not be handled.

7. *Centrifugal force* is an interesting study in itself. Read all you can find about it in reference books. Then see how many machines you can find that use it. (You use it in a spring window-shade roller each time you raise the shade. How?)

8. Read in a reference book about *differential pulleys* to learn what they are and how they work. Then look for differential pulleys in garages and machine shops.

9. Barber's chairs, jacks for lifting trucks, and many other devices now make use of the *hydraulic press* principle. Find out how hydraulic presses work.

10. Study the mechanical brake system in a car. Make a diagram to show the different simple devices used.

11. Would you place the load in a wheelbarrow near the wheel or near the handles? Make a drawing to explain your answer.

## Books to Read

Bock, G. E. *What Makes the Wheels Go 'Round?* (pages 1-18). Macmillan, 1931.

Bowden, G. A. *Foundations of Science* (pages 327-350). Blakiston, 1931.

Collins, A. F. *Experimental Mechanics*. Appleton-Century, 1931.

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Dull, Charles E. *Modern Physics* (Units 4 and 5). Holt, 1939.

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Hylander, C. J. *American Inventors* (pages 27-34, 59-72, 109-116). Macmillan, 1934.

Meister, Morris. *Living in a World of Science: Energy and Power* (pages 120-166). Scribners, 1935.

Morgan, Alfred P. *Boys' Home Book of Science and Construction* (pages 73-122). Lothrop, 1921.

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Wilson, Grove. *Great Men of Science* (pages 43-52). Garden City, 1932.

PEOPLE HAVE ALWAYS BEEN INTERESTED IN THE EARTH, the sun, the moon, and the stars. For thousands of years they did not understand what these heavenly bodies were, but they collected a great deal of information about them. When the telescope was invented, men began to learn the explanations of the things they had seen in the heavens. In this unit you will learn some of the important things that scientists have discovered about the earth and the other heavenly bodies. (Bettmann photo)

# UNIT 13

# What Is the Relation of the Earth to Other Heavenly Bodies?

## Looking Ahead to Unit 13

ALMOST EVERYONE SPENDS MANY HOURS of his life wondering about the world we live in. Even savage people who can neither read nor write are puzzled by the sun, the moon, the stars, and the coming of day and night and of the seasons. We know this because they tell stories to explain why the moon changes its shape, why the stars "come out" at night, why the sun "goes down," and other things that they see happening from day to day and from month to month. Men and women and boys and girls have always wondered about the earth and the heavens. Books and other records made by people thousands of years ago tell us that these ancient ancestors of ours were asking themselves the same questions about the world that we ask today. The human mind is always the same wherever you find it. It is a questioning mind. It wants to know why. It is not satisfied with just knowing that things do happen. It wants to know what causes things to happen in the way they do.

Of course, a few thousand years ago men had few ways of satisfying their curiosity about what they saw. But as time went on, they gathered a great deal of information about the stars and the other heavenly bodies. Clever men, called *astrologers*, were able to take this information and foretell when an eclipse was coming, where the stars would be at different times of the year, and many other events concerning the heavenly bodies. People believed that if astrologers could foretell happenings in the heavens from the study of stars, they could also foretell events in people's lives. Until a few hundred years ago every king had his astrologer, whose advice was asked on all matters of importance

FIG. 287. This old engraving, made in 1560, shows an early astronomer in his study. He seems to be studying and checking the ideas of other scientists from a book. Perhaps he is going to make a chart showing the probable locations of the stars and other heavenly bodies that he has observed. (Bettmann photo)

Most of us know now that the position of the stars or the planets has no influence whatever on our lives. But even today you will find people who believe in *astrology*; that is, they believe that their future can be foretold by the positions of the stars on the day they were born. This is an example of how old ideas, even though they are proved to be false, are believed and passed on from generation to generation.

For thousands of years people had wrong beliefs about the sun, the earth, and the stars. But there were always a few honest, careful thinkers who tried to find the true answers to the questions that came up in their minds. Because of these men, a new science gradually developed, the science of *astronomy*. When the telescope was invented in 1608, the astronomer had an instrument that helped him prove or disprove many of the ideas that were commonly believed. With this instrument he also learned many new facts. The science of mathematics had been developed, and astronomers could "figure things out" in ways that they had never before been able to use. And today the astronomer can take pictures of the heavenly bodies and study them. He can even get pictures of stars that he cannot see!

In this unit you will learn some of the things that scientists have discovered about the nature of the world in which we live.

For example, scientists believe that our sun is a star, similar to the other thousands of stars that you can see on a clear, moonless night. Why does it appear so much larger than the other stars? How do we know that the earth rotates on its axis and revolves around the sun? How can the rotation of the earth on its axis be used as a clock? Why do the other planets shine? Is it probable that the other planets are inhabited? Why does the moon appear to change its shape? What is the cause of eclipses of the sun and moon? These questions and others have been the subject of man's investigation for thousands of years. In this unit you will find the answers. You will know more about the universe than the wisest man of three or four hundred years ago.

## ¶ 1. What is the solar system?

WHAT IS THE SUN? As you look into space on a clear day, there is one object that you always see. This object is more than 93,000,000 miles away, but you could not live without it. Fortunately, we could not get away from this object if we tried. It holds the earth as a prisoner. Year in and year out, the earth is travelling at a speed of over 1000 miles a minute around and around this object. As you have guessed, this object is the sun. It is the centre around which the earth and certain other heavenly bodies keep up a never-ending journey. The sun and the heavenly bodies that revolve around it are called the *solar system*.

Have you ever wondered what the sun is really like? You know that the sun is very hot, because it gives the earth a great amount of heat and light even though it is millions of miles away. To give us this enormous amount of heat and light at so great a distance, the sun must be very much hotter than anything we can imagine; and so it is. Scientists have measured the temperature of the outside of the sun. It is about 10,000° F. They believe that the temperature in the centre of the sun is many million degrees. At this temperature solids and liquids could not exist. So the sun must be a huge mass of extremely hot gases.

You would never guess how huge this ball is, but scientists can tell you because they have actually been able to measure it. They say that it would take more than 100 bodies the size of the earth

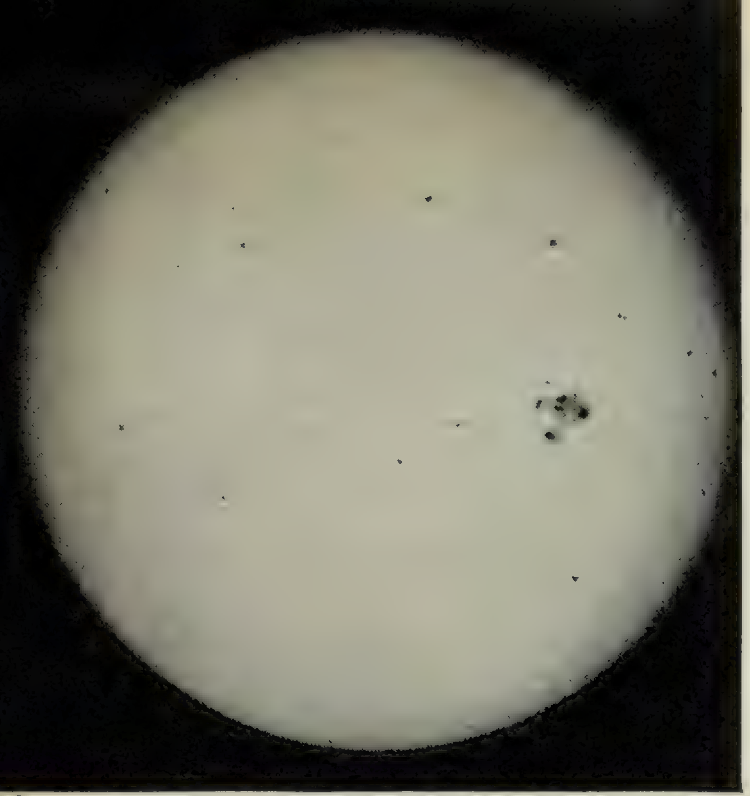

Fig. 288. Astronomers say that sun-spots of average size, such as shown in this picture, would hold forty planets the size of the earth. (Yerkes Observatory photo)

Fig. 289. Great flaming masses of gases are frequently shot off into space thousands of miles from the surface of the sun. (Yerkes Observatory photo)

placed side by side to equal the diameter of the sun. If the sun were hollow, there would be room enough inside it for more than 1,000,000 earths. It looks small to us because it is so far away.

Photographs of the sun, taken through powerful telescopes, have shown scientists many interesting things about what is happening on it. For one thing, there are at times great swirling masses of gases on the surface of the sun. Scientists speak of these as "storms" on the sun and call them *sun-spots* (Figure 288). These storms are called "spots" because in the photographs they show as dark spots. It is fortunate that we are far from the sun. If we were very close, one such storm would destroy the earth. Many scientists think that sun-spots cause unusual weather conditions on the earth.

You have often seen the *stars* in the heavens at night. Astronomers find out about the stars by studying the light that comes from them. They find that it is the same kind of light as the light from the sun. From this they know that the sun itself is a star. The sun looks larger and brighter than the other stars because we are close to it. The sun is our nearest star.

WHAT ARE THE PLANETS? Long before telescopes were invented, people noticed heavenly bodies that looked like stars, but that were different from stars in the way they moved across the sky. They gave the name *planets*, or wanderers, to

these bodies. Since scientists began to study the heavens, they have learned many things about the planets. They have discovered three planets that are too dim to be seen without a telescope. They have found that the planets seem to move among the stars because the planets are travelling in paths around the sun. They have learned that the earth itself is a planet. We now know that there are at least nine planets. Pluto, the last one to be discovered, was not found until 1930. And there may be others still farther from the sun.

So far as astronomers have been able to tell, the planets are all made of material somewhat like the earth. Some of them have an atmosphere with clouds, as the earth has. Since the planets are much like the earth, they cannot give out light as the stars do. We can see them "shining" in the night skies because the sun shines on them, and they reflect the light back to us.

Figure 290 shows a diagram of the nine planets and the paths, or *orbits*, in which they revolve about the sun. As you can see, two of these planets, Mercury and Venus, are much nearer the sun than the earth is; therefore, they must be much hotter than the earth. Because these two planets are nearer the sun, they do not have such great distances to travel to make a complete journey around the sun. Also, they travel faster than the planets farther away from the sun. So they complete their revolutions more quickly than the earth does. The earth is the third planet from the sun. We know that it travels around the sun once in approximately 365¼ days and that it turns on its own axis once every twenty-four hours.

Planets farther out from the sun are Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. They all have greater distances to travel in going around the sun than the earth does, and they travel more slowly than the planets nearer the sun; so they require longer periods in which to complete their revolutions. Because of their greater distances from the sun, they do not receive so much light or heat as the earth; therefore scientists believe that they are colder than the earth.

By studying Table 16, page 420, you can learn the most important facts about the planets. As you can see, Mercury is the nearest of all planets to the sun. Its distance is about 36 million

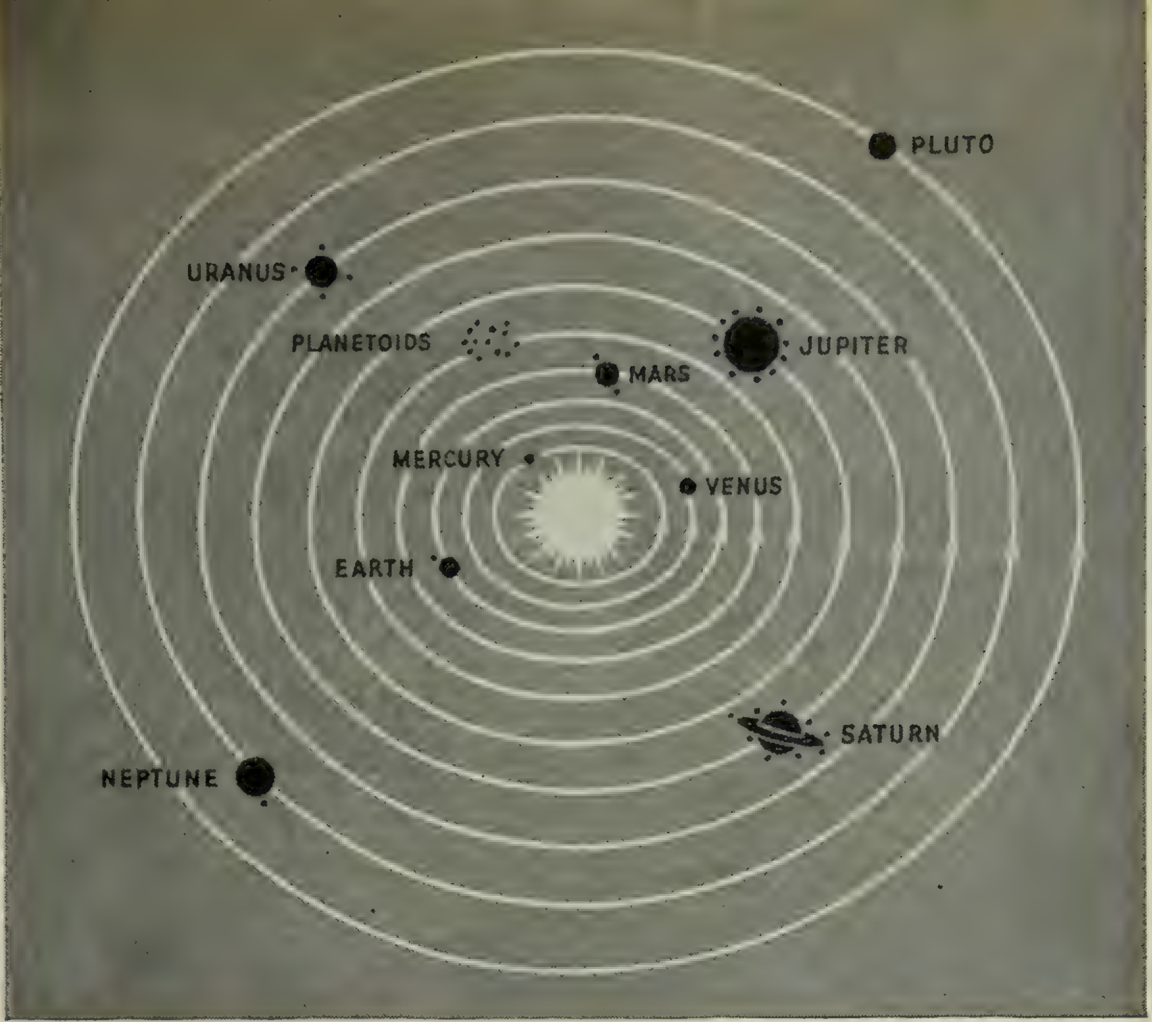

FIG. 290. The earth and the eight other planets revolve about the sun in the same direction. In this drawing it was not possible to show the distances between the paths of the planets in their correct relations to each other. Table 16 tells how far the various planets are from the sun.

miles, while the distance of the earth is about 93,000,000 miles. Mercury is a small planet—only about half as large in diameter as the earth. It requires only eighty-eight days to go around the sun. In other words, Mercury goes around the sun about four times while the earth is going around once. Mercury turns very slowly on its axis. The earth spins around once every twenty-four hours, but Mercury turns only once in approximately eighty-eight days. You can see that it turns upon its axis only once while it makes a complete revolution about the sun. Because of this, the same side of Mercury is always turned toward the sun. As a result, the side toward the sun must be extremely hot, and the side away from the sun must be extremely cold.

In Figure 290, above, you will notice that there is a vast distance between the orbits of Mars and Jupiter. In this space between Mars and Jupiter scientists have found about 1100 small bodies that are like tiny planets. These bodies vary in diameter from 20 to 300 miles. They are called *planetoids*, which means little planets. They travel around the sun in their own orbits. Scientists think that these planetoids may be pieces of a big

TABLE 16. IMPORTANT FACTS ABOUT THE SOLAR SYSTEM

| BODIES | DISTANCE FROM THE SUN | DIAMETER IN MILES | REVOLUTION AROUND SUN | ROTATION ON AXIS | APPROXIMATE TEMPERATURES | APPEARANCE IN NIGHT SKIES | MOONS | SPEED IN MILES PER SECOND |
|---|---|---|---|---|---|---|---|---|
| Sun | .............. | 864,392 | .......... | 25 days | 10,000° F. at surface | ............ | ...... | ........ |
| Mercury | 36 million miles | 3,009 | 88 days | Nearly 88 days | Hot on one side, cold on other | Reddish-yellow | 0 | 29.7 |
| Venus | 67 million miles | 7,701 | 225 days | 224.7 days | Hot on one side, cold on other | White | 0 | 21.7 |
| Earth | 93 million miles | 7,918 | $365\frac{1}{4}$ days | 23 hrs. 56 min. | Sufficient to support life | ............ | 1 | 18.5 |
| Mars | 142 million miles | 4,339 | 687 days | 24 hrs. 37 min. | Colder than earth | Red | 2 | 15.0 |
| Jupiter | 483 million miles | 88,392 | $11\frac{7}{8}$ years | 9 hrs. 53 min. | Very cold | Yellowish-white | 11 | 8.1 |
| Planetoids | 200 or 300 million miles | 20 to 300 | 2 to 13 years | Unknown | ................ | Not usually visible | ...... | ........ |
| Saturn | 886 million miles | 74,163 | $29\frac{1}{2}$ years | 10 hrs. 15 min. | Very cold | Reddish-yellow | 9 and 3 rings | 6.0 |
| Uranus | 1,782 million miles | 30,193 | 84 years | 10 hrs. 42 min. | Very cold | Barely visible to naked eye | 4 | 4.2 |
| Neptune | 2,792 million miles | 34,823 | $164\frac{1}{2}$ years | 15 hrs. | Very cold | Not visible to naked eye | 1 | 3.4 |
| Pluto | 3,673 (?) million miles | Less than 10,000 (?) | 247.7 years | Unknown | Very cold | Not visible to naked eye | ? | 2.9 |
| The Earth's Moon | 93 million miles (variable) | 2,163 | .......... | 27.6 days | Hot on one side, cold on other | Yellowish-white | ...... | ........ |

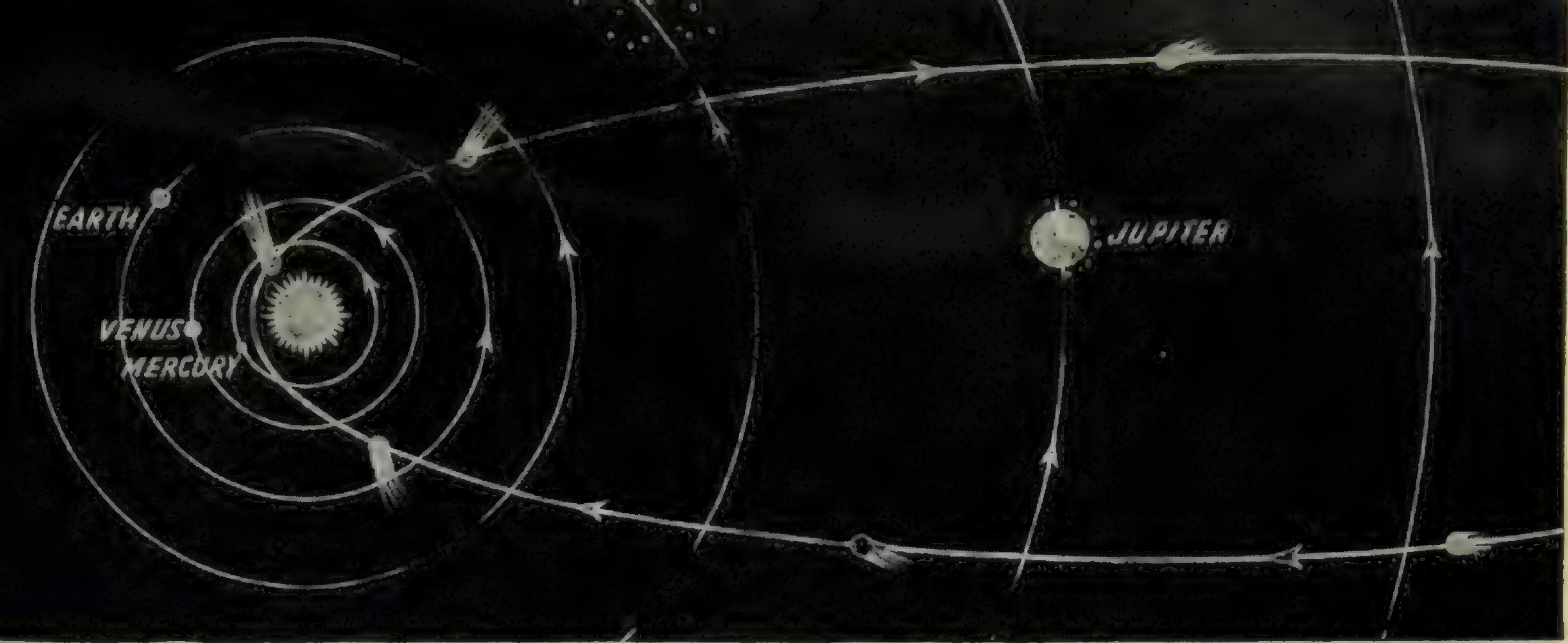


FIG. 291. The strangest thing about a comet is that, during its entire trip about the sun, its long tail streams away from the sun. When it approaches the sun, the tail is behind it. When it swings away from the sun, the tail is out in front.

planet that once upon a time travelled around the sun between Mars and Jupiter. They think that this big planet may have met with some kind of accident that broke it to pieces.

WHAT ARE COMETS AND METEORS? Another strange kind of heavenly body that sometimes appears in the solar system is known as a *comet*. Scientists believe that comets are masses of gaseous material. Some of them have long gaseous tails that are always on the side away from the sun. Comets travel in very loop-shaped, or elliptical, orbits around the sun (Figure 291). Some are known to return at intervals of from three to 75 years.

*Meteors* are heavenly bodies that we see more often. We usually call them "falling stars," but this name is incorrect. Stars do not fall. Meteors are really small bodies of material that fall from space into the earth's atmosphere. No one knows where they come from. Sometimes they are only as large as a pea; sometimes they weigh several tons. Only when these bodies fall into the earth's atmosphere do we see them. The air rubbing against them as they fall causes them to become very hot and give off light. Sometimes meteors fall to the earth. Then we call them *meteorites*. Some meteorites are found to be stones, and some are masses of metal, mostly nickel and iron. Usually the meteorites burn up, and only the dust that is left falls to the earth.

*Moons*, or *satellites*, are also found in the solar system. Moons are bodies that revolve around planets much as planets revolve around the sun. From Table 16 you can see that some planets have many moons. As you know, the earth has only one.

*Self-Testing Exercises.* 1. Tell briefly what you think of when someone mentions the solar system.

2. How did scientists learn that the sun is itself a star?

3. Do scientists think that the inside of the sun is solid, liquid, or gaseous? Give one reason for their belief.

4. What is a planet? Do planets give light themselves? Explain.

5. Name the planets that have orbits inside the orbit of the earth. Name those that move outside the earth's orbit.

FIG. 292. This meteorite is the largest ever seen to fall. It is two and one-half feet long and weighs 820 lbs. The largest known meteorite in North America weighs 36½ tons. (Underwood and Underwood photo)

6. State three ways in which Mercury is different from the earth.

7. Which planet would you expect to be the warmest? Which one the coldest? Why?

8. How are planetoids different from planets?

9. What is a comet?

10. What is a meteor? Why do meteors give out light?

*Problems to Solve.* 1. Which planet has the longest year? Which the longest known day?

2. Which planets were discovered with the help of the telescope? You can solve this problem from the reading and Table 16.

3. From Table 16 and from what you know about the planets make a list of the ways in which they are alike. Make also a list of the ways in which they are different. (One way in which they are different is in "Size." Do not say, "Mercury is smaller than the earth.")

4. If you could fly from the earth to the sun at a rate of 200 miles per hour, how many years would it take you if you flew 24 hours per day?

5. Draw circles to represent the sizes of the nine planets. Make the circle for Mercury one-fourth inch in diameter and calculate from Table 16 how large each of the other circles should be.

6. How are planets different from stars? List all differences.

7. Find in reference books as many interesting facts about Venus as you can. Do the same for Mars, Jupiter, and Saturn.

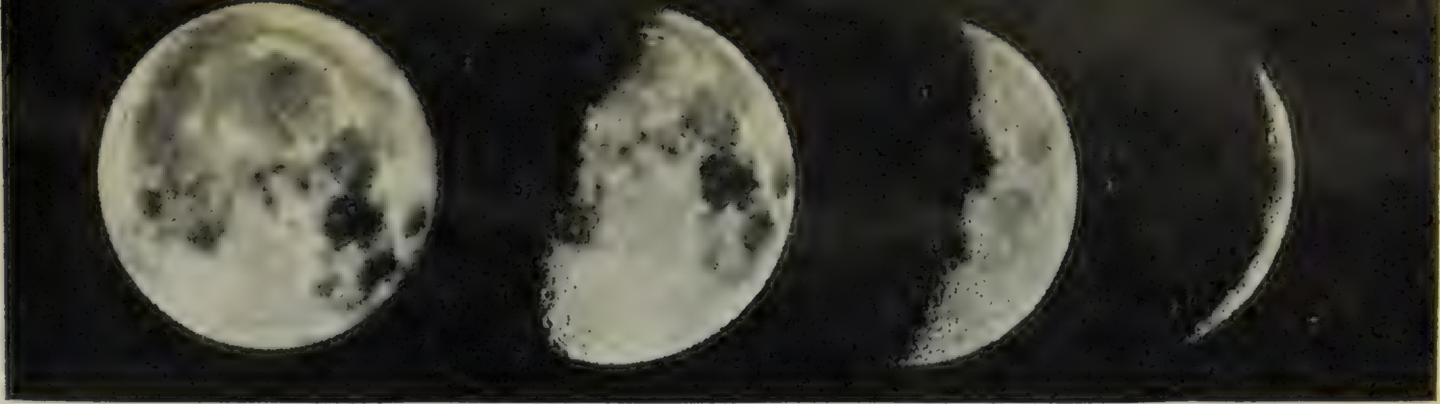

FIG. 293. This picture shows how the moon changes from a crescent-shaped new moon to a round full moon. Each of these different shapes is called a *phase* of the moon. Beginning at the right the moon is shown at the ages of 3.85 days, 5 days, 9¾ days and 16 days. (Yerkes Observatory photo)

WHAT IS THE EARTH'S MOON LIKE? The heavenly body we notice most often is the sun. But our nearest neighbor in the heavens is the moon. Strangely enough, there are times when we do not see it at all. When we do see it, we find that it apparently changes its shape from day to day. Sometimes it looks like a full circle, at other times like a half circle, and at other times like a crescent. Of course we know that the moon does not change its shape. Why, then, does it seem to do so?

As you look at the full moon in the sky, it seems to be about the same size as the sun. Actually, its diameter is only a little over 2000 miles, about one-fourth the diameter of the earth. It would take about 400 moons side by side to make a body with the same diameter as the sun. The moon appears to be as large as the sun because it is so much closer to us. It is only about 240,000 miles from the earth. This may seem like a great distance, but it is a very small distance as compared with the 93,000,000 miles to the sun.

Moonlight, as you know, is not nearly so bright as sunlight. The moon is not made of hot gases; it gives off no light of its own. We see the moon because the light from the sun strikes it, and this light is reflected to the earth. Imagine that you are in a dark room with a large, very white ball and a bright flashlight. You then hang the ball up by a string and turn the flashlight on the ball. You find that the wall behind you is lighted up with light reflected from the ball. The moon reflects the light of the sun to us just as the ball reflects the light from a flashlight.

When the moon is full, you can see irregular spots that appear darker than others. If your imagination is good, you can see that these spots make the eyes, nose, and mouth of the "man in the moon." If your imagination is still better, you may see the lady

Fig. 294. Seen through a telescope, parts of the moon's surface have a pitted appearance. These pits are immense craters. Other parts of the moon's surface are rough while others are smooth. (Underwood and Underwood photo)

in the moon. Until telescopes were invented, no one knew why these spots were there. Through the telescope, however, we can see that these spots are really chains of mountains, great craters, and vast flat spaces.

What you have just read might lead you to believe that the moon is somewhat like the earth. It is, however, quite different. The mountains are more rugged, and they rise almost straight up from the plains. One of the most amazing things about the surface of the moon is the tremendous number of craters. Over 30,000 of these craters have been found. They are many times as large as any of the volcano craters found on earth. One of the moon's craters is seventy-five miles in diameter, while there are hundreds of smaller craters that are from five to twenty miles in diameter. Story-tellers often write tales of the strange creatures on the moon. These stories, however, are not based on any facts that we know. The moon can have no living creatures on it, because it has no air, water, or soil. Our nearest companion in space is just a huge ball of barren rock.

Why does the moon seem to change its shape? You know that the moon, like the earth, is a sphere. At any one time only half of it can be lighted by the sun. You also know that the moon revolves around the earth in twenty-seven and one-third days. As it travels around the earth, we see different parts of its surface lighted by the sun. You can best understand why this is true by doing an experiment.

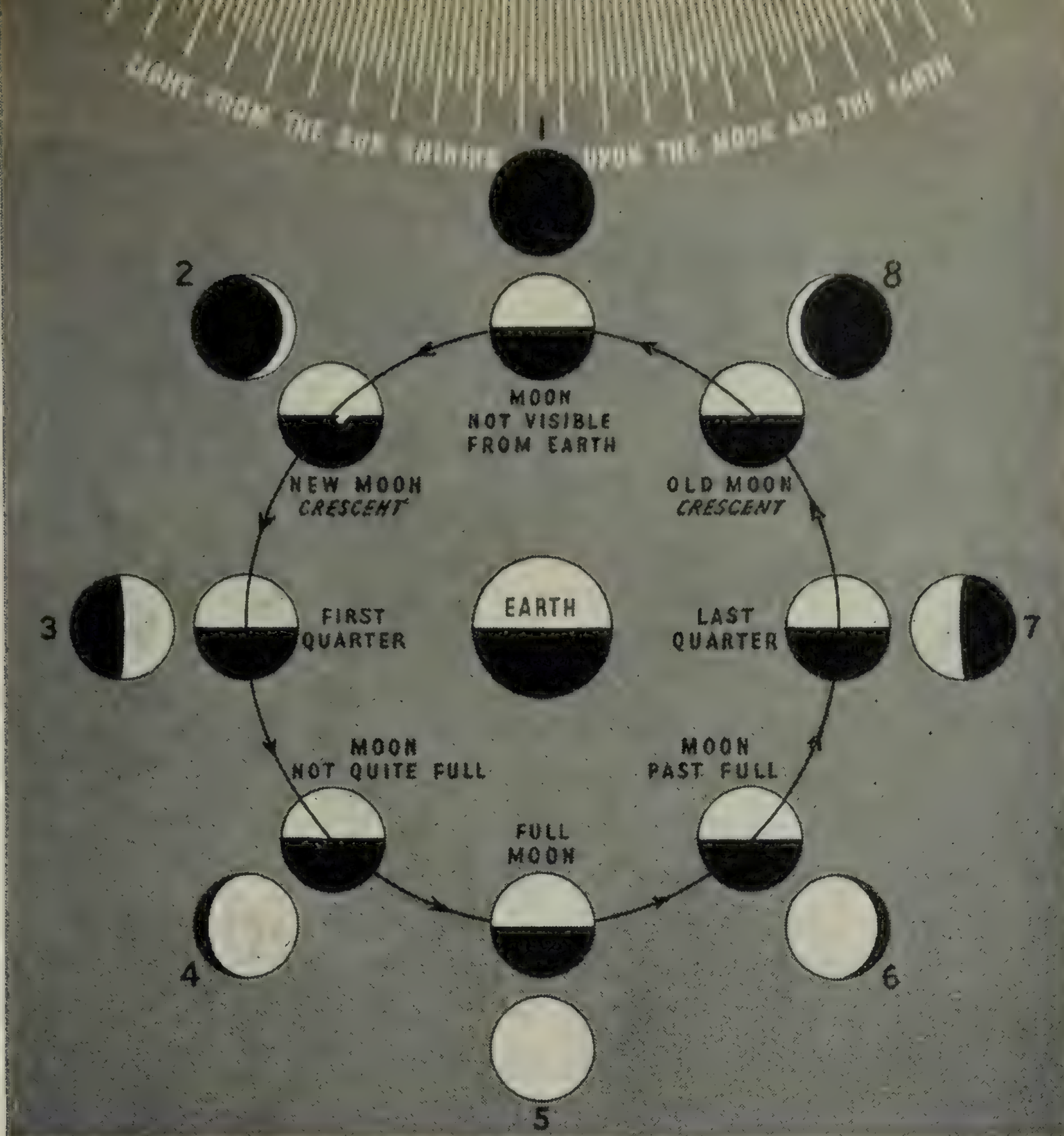


FIG. 295. The outer circles show the shape of the lighted part of the moon as it appears to us on the earth at different times of the month. The inner circles show the moon as it is actually lighted. The half that is toward the sun is always lighted. The only portion of this lighted half that is visible to us on the earth is that inside the black line.

*Experiment 70.* WHY DOES THE MOON APPEAR TO HAVE DIFFERENT SHAPES AT DIFFERENT TIMES? Place a strong light upon a stand about four feet high to represent the sun as in Figure 295. You are to represent the earth. Hold a tennis ball at arm's length from you to represent the moon. Stand with your face to the light and hold the ball between you and the light, as shown in position 1, Figure 295. The half of the ball nearest you should be entirely dark.

Now turn toward your left, away from the light, stopping at each of the numbered positions shown on the diagram. Hold the ball high enough above your head to receive the light in position 5. Can you see each of the shapes shown in the outer group of circles as you change positions?

Sketch the shape of the lighted parts of the ball in each position. How do these shapes compare with the shapes of the moon as it appears to you at different times?

Figure 295 and your experiment will help you see why the moon appears to change its shape. When you held the tennis ball between yourself and the light, the half of the ball nearest the light was lighted, but the part toward you was dark. In the same way, you cannot see the moon when it is between the earth and the sun. With the ball held at one side, you could see half of the lighted surface. When the earth, sun, and moon are in this position, you see the *quarter moon.* When you were between the light and the ball, you could see all of its lighted part. When the earth is between the sun and the moon, you see the *full moon* because the light from the sun shines over the earth and on to the moon. As you moved the ball around, you found that you could see different amounts of the lighted parts. This is what happens when the moon revolves around the earth.


FIG. 296. Eclipse of the moon


FIG. 297. Eclipse of the sun

Sometimes the sun, moon, and earth get in a direct line, as shown in Figure 296. Then the moon gets in the earth's shadow. This causes the moon to appear partly or totally darkened. This is called an *eclipse* of the moon. At other times the sun, moon, and earth get in the direct-line position that is shown in Figure 297. The moon comes between the earth and the sun. This throws the moon's shadow upon the surface of the earth. When we look at the sun, we see its surface totally or partly darkened, depending upon where we are upon the earth. Then we have an eclipse of the sun. In July, 1945, the moon caused a total eclipse of the sun along a path in the northwestern United States and Canada.

FIG. 298. The same seashore is shown at low tide, on the left, and at high tide, on the right. (Century photos)

HOW DO THE MOON AND THE SUN CAUSE TIDES? As you know, the earth has gravity. That is, it attracts everything toward itself. The gravity of the earth is so powerful that it even holds the moon in its orbit. Scientists have found that all the heavenly bodies have an attraction for other bodies. The sun holds the planets in their orbits, and each planet attracts its moons. Our moon has an attraction of its own and pulls on the earth. It pulls both the land and the water, but the water moves more easily than the land. Therefore, the water is pulled up on the side of the earth nearest the moon. As the earth turns, the pulled-up water soon reaches the shore and makes a tide there. When this happens, we say that there is a *high tide*.

The earth turns rapidly upon its axis, and soon the part of the ocean that was nearest the moon (where the water bulges out) turns away from the moon. Then the water settles back, and we have *low tide*. The strangest thing about the tides, however, is another high tide on the side of the earth away from the moon. The moon seems to pull harder on the solid part of the earth than it does on the water that is on the side farthest away from the moon. Thus, the water also bulges out on the side away from the moon. When the earth turns half-way around so that we are farthest away from the moon, we have high tide again. At some places there is a difference of as much as fifty feet in the depth of the water between high and low tides.

As the earth turns upon its axis, two high tides take place at any point on the ocean's shore every twenty-four hours and fifty minutes. Of course, there are also two low tides during this same period of time. So we have a high tide and a low tide alternating about every six hours and twelve minutes. The sun's attraction for the earth also affects the tides. Twice a month it makes the tides unusually high, and twice a month it works against the

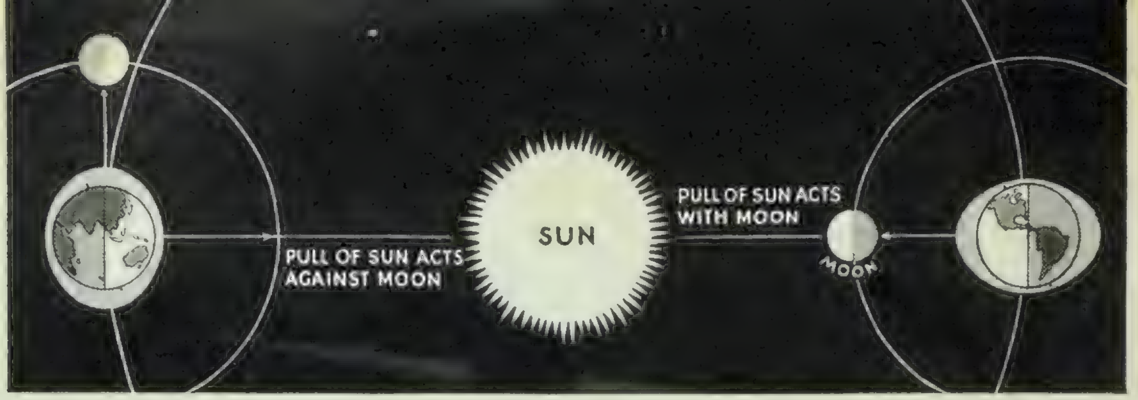


FIG. 299. This diagram shows how the sun and the moon pull together and cause high tides at certain times of the month. It also shows how they work against each other and cause low tides at other times during the month.

moon so that tides are unusually low. Figure 299 shows the positions of the sun, the moon, and the earth when the tides are unusually high and unusually low.

*Self-Testing Exercises.* 1. What is the difference between sunshine and moonshine?

2. Why do we believe that there is no life on the moon?

3. Write a paragraph telling why the moon appears to change its shape.

4. What can people on the earth see happening during an eclipse of the moon that they cannot see at other times? Why does this happen?

5. Answer Exercise 4 for an eclipse of the sun.

6. How many high tides does a city on the ocean have during twenty-four hours?

7. How does the moon cause tides?

*Problems to Solve.* 1. With a light, a large ball, and a small one show how eclipses of the sun and moon happen. You may use your head instead of a large ball to represent the earth.

2. The new moon, first quarter, full moon, and last quarter are known as the *phases* of the moon. At which phase of the moon does an eclipse of the moon occur?

3. At which phase of the moon does an eclipse of the sun take place?

4. The sun helps the moon make an unusually high tide during two phases of the moon. Which phases are these? Why?

5. Some people say moonlight is really sunlight. Is this true? Explain.

6. The moon always turns the same side toward the earth. Does it always keep the same side toward the sun? Explain.

7. You can make a scale model that shows the earth and moon and the distance between them. Use a ball two or three inches in diameter for the earth. Then calculate how large the "moon" should

be and make it from clay or some other material that you can cut or mold to size. Calculate how far apart the balls should be and fasten them on a long board with nails. This model will help you solve Problem 8.

8. Can you think or find out why there is not an eclipse of the moon each month when the moon is on the opposite side of the earth from the sun?

9. On the scale you used in Problem 7 how far away and how large should the sun be?

## 2. What is the nature of the universe?

How large is the universe? We have learned that the sun is a star. It has a family of planets, moons, and comets circling about it. All the other stars, or suns, are so far away in space that they look like points of light. Many of these distant suns may have their own families of heavenly bodies travelling about them. When we wish to talk about all the stars out in space, with all the other heavenly bodies, we speak of the *universe*. That is, the universe is everything that exists in space.

To us, who live on the earth, it seems that the earth must be a very important body. Of course, it is important to us, but is it a really important part of the entire universe? To answer this question we shall need to find out more about the universe. You already know that the sun is so large that it would hold about a million earths. As compared with other stars, however, our sun is only medium-sized. Betelgeuse, one of the large stars, would hold about 27,000,000 suns and about 27,000,000,000,000 (twenty-seven trillion) earths. So far as size goes, you can see that the earth is a very unimportant, tiny body.

When you look into the skies on a dark night, you can see fewer than 5000 stars with your naked eye. But with one of the most powerful telescopes on this continent, about fifteen hundred million stars can be seen. This number, scientists believe, is only a small fraction of the number of stars in the heavens. Such a number is, of course, so large that we cannot even imagine it.

When you travel on earth, a thousand miles is a fairly long trip. If you were to travel through the universe, a trip of a thou-

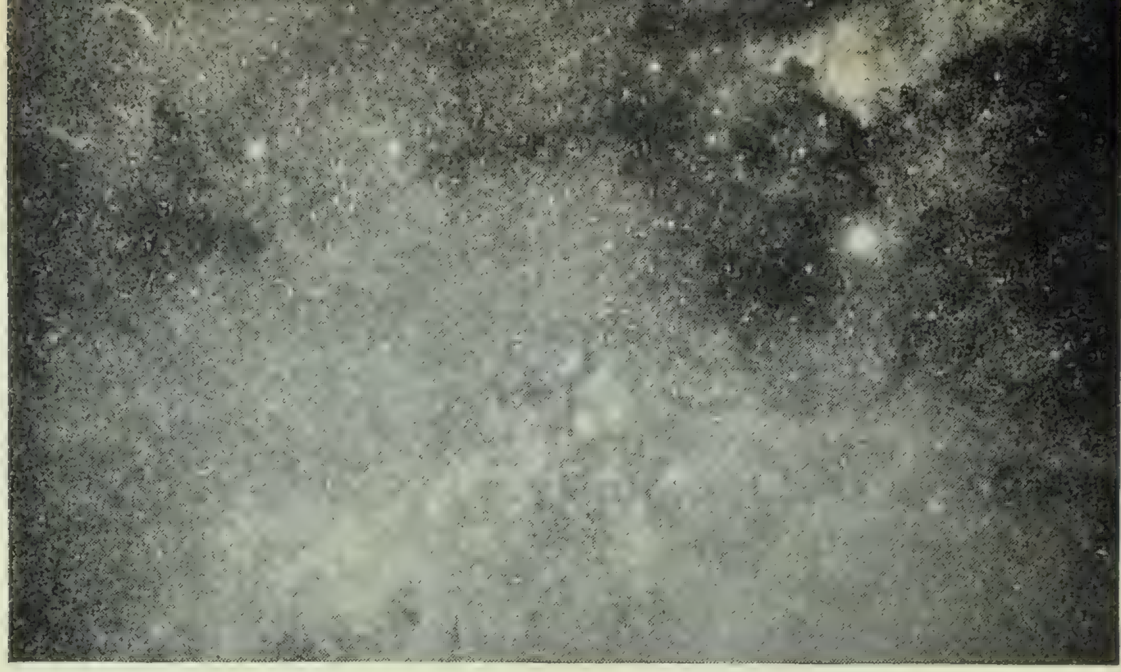

FIG. 300. Have you ever looked up into the *Milky Way* and wondered what it really is? The first observation with telescopes astonished astronomers by showing them that the Milky Way is made up of myriads of stars. In other parts of the sky not nearly so many stars can be seen. (Yerkes Observatory photo)

sand miles would get you nowhere. Distances are so great in the universe that instead of using the mile as a measure of distance, the astronomer uses a *light-year*. A light-year is the distance that light travels in one year. Light travels at the rate of 186,000 miles a second. To find out how large a light-year is, you must first multiply $186{,}000 \times 60 \times 60 \times 24$. This will give you the distance light travels in one day. Then you must multiply by 365¼ (the number of days in a year). If you multiply these numbers, you will find that light travels about 5,869,713,600,000 miles in a year.

The nearest star to us (except the sun) is 4.27 light-years away. How many miles away would this be? The North Star is about forty light-years away. Astronomers have seen some clusters of stars that are a million light-years away. When you see how far away these stars are, you can understand why the astronomer does not use the mile as a unit of measurement. Here again the numbers that represent distances in the universe are so great that we cannot even imagine how enormous the universe really is.

WHAT IS THE SHAPE OF OUR GALAXY? As you look at the heavens, the stars seem to be scattered across the sky in great confusion. But that is not true. As men have learned more about the universe, they have found that the heavenly bodies have an orderly arrangement. They have also learned that the vast spaces out beyond the earth are not crowded with heavenly bodies even though they may seem to be. Space is really very

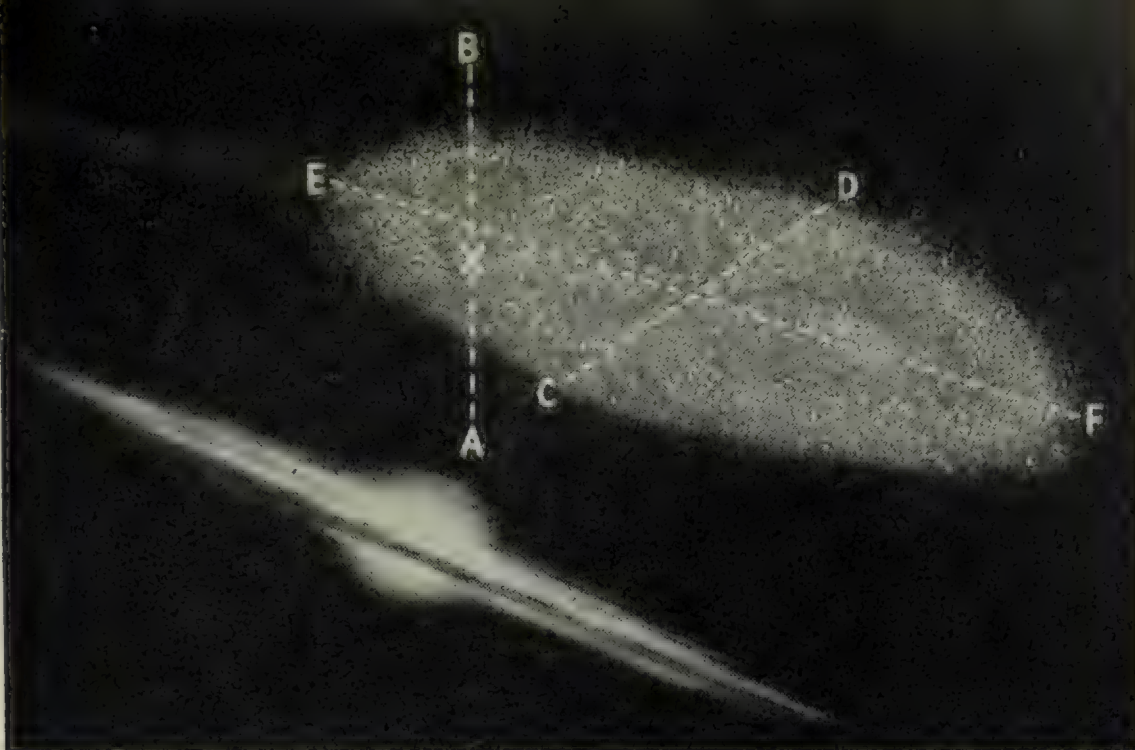


FIG. 301. The diagram at the top shows a slanting view of our galaxy as we imagine it would appear if we could look down upon it. The diagram at the bottom shows how scientists believe the galaxy would appear if we could look at it edgewise. You can see that the center of our galaxy is much thicker than the edges.

empty when we consider how vast the distances are between the heavenly bodies.

Astronomers believe that the solar system, including the sun and all the stars that we see at night, is part of a great star group, or *galaxy*. Our own galaxy seems to have a flat, disk-like shape, somewhat like a watch. This galaxy is much wider than it is thick (Figure 301). The solar system is located in this group of stars near the place marked X in Figure 301. When you look out into the heavens at night toward point A or point B, you see comparatively few stars sprinkled over the skies. But when you look toward points C, D, E, or F, you are looking toward the farthest edges of the galaxy. Therefore you see many more stars when you look into these parts of the heavens. These stars appear as a band of light across the sky. We call this band of light the *Milky Way*.

However, you must not get the idea that the stars in the Milky Way are crowded as close together as they appear to be. On the contrary, the stars are very far apart. They merely appear to be close together when we look at them, because we are looking through such a great number of them.

Now the question arises, Does our galaxy contain all of the stars that exist? Astronomers think not. By means of very high-powered telescopes they have discovered about two million

Fig. 302. The glowing disk, called the Great Nebula of Andromeda, is made up of tens of thousands of millions of suns. It is 800,000 light years away from the earth. If you travelled as fast as light (186,000 miles per second) straight out into space without stopping, it would take you nearly a million years to reach this nebula.

irregular-shaped, glowing masses of material called *nebulae* (singular, *nebula*). These nebulae, far outside of our own galaxy, are believed to be other galaxies of stars. A few of the nebulae seem to be masses of glowing gas that may be developing into clusters of stars. If we stop to think that probably each of these countless nebulae contains as many stars as our own galaxy contains, we are staggered by the immense size of the universe. And when we remember that these millions of heavenly bodies are hundreds of millions and even billions of miles apart from each other it is quite beyond our powers of imagination to realize just how large all of the space in the universe is.

How can we learn to name the stars? For many centuries people have enjoyed looking into the heavens upon dark nights and finding the stars that they know. Many of the brighter stars were well-known to the ancients. The beauty of the great dog star, Sirius, filled the early Egyptians with awe, and Job, in the Bible, spoke of the star Arcturus. Long ago, lone shepherds watching their flocks at night imagined they saw pictures made in the skies by different groups of stars. They gave the names of animals, kings, queens, and their gods to these star pictures. Today we still find these sky pictures, and we still use the names that were given them by the people of long ago. Such groups of stars are called *constellations*.


FIG. 303. Constellations that circle around the North Star night after night

The stars appear to rise and set just as the sun and moon do, but this is because the earth itself is turning. However, if you watch the northern heavens at night, you will discover that many of the stars do not "set." One star, the North Star, appears to stand still while the other stars seem to move around it in circles. The North Star seems to stand still because it is almost exactly above the North Pole of the earth. You are probably familiar with the Big Dipper (Ursa Major) and the Little Dipper (Ursa Minor). The two end stars in the bowl of the Big Dipper will help you find the North Star and the Little Dipper. On some dark, clear night try to find the constellations shown in Figure 303. Cepheus, Cassiopeia, and Draco, the dragon, are other constellations that can be seen in the northern sky on almost any clear night.

Almost anyone can learn to locate some of the more prominent constellations. As the earth moves around the sun during the year, the side of the earth that is dark is turned toward different parts of the heavens as the year goes on, until finally it comes back to the same part of the heavens again. For this reason some constellations that can be seen during one season of the year are invisible during another season. Figures 304 and 305 show maps of the stars that can be seen in the eastern sky in autumn and in spring.


FIG. 304. Some of the constellations and stars shown on the autumn map are: Taurus, the bull, with the red star Aldebaran; Auriga with the gold star Capella; Cetus, the monster; Aries, the ram; Pisces, the fish; Cassiopeia, the queen in her chair; Andromeda, the daughter of Cassiopeia; Perseus, who rescued Andromeda; and Pegasus, the winged horse, which has no very bright stars in it. Locate the constellations on this sky map and then try to find them in the eastern skies during the autumn.

*Self-Testing Exercises.* 1. Tell what the term *universe* means to you.

2. What is a constellation?

3. What is a light year? Why do astronomers use light years?

4. Why do the constellations of the northern skies seem to circle about the North Star?

5. Use the words listed to fill in the blanks below.

*star(s) moons planets planetoids galaxies comets universe*

*a*) The universe is composed of ............

*b*) A galaxy is composed of ............

*c*) The solar system is composed of ............, ............, ............, ............, and ............

6. Why do we see different constellations at different seasons?

7. Why does the Milky Way appear so light?

8. What is the shape of our own galaxy?

9. How long would it take an aeroplane flying at a rate of 200 miles an hour to reach the North Star? (See page 430.)

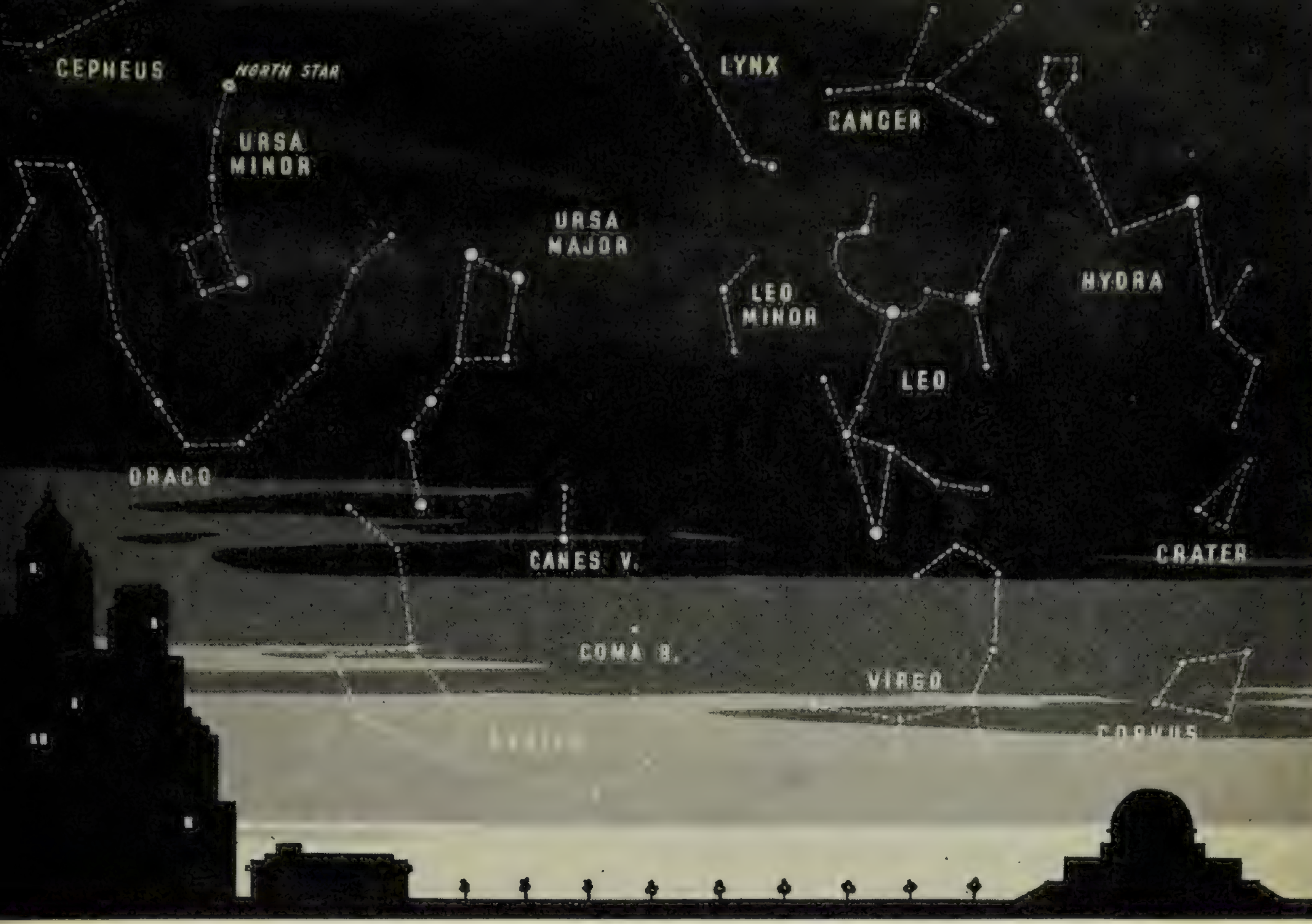


FIG. 305. Some of the constellations of the spring skies are: Boötes, the plowman, with the yellow-orange star Arcturus; Leo, the lion, with the red star Regulus; Virgo, with the white star Spica; Draco, the dragon; Hydra, the serpent; Corvus, the crow; Crater, the cup. Locate these constellations and stars on this spring sky map and then try to locate them for yourself in the eastern skies in the spring.

## 3. How do the earth's movements affect us?

IS IT HARD FOR YOU TO BELIEVE that you are living on a body that is moving faster than an aeroplane? The earth travels, or revolves, around the sun in one year at a speed of 66,000 miles an hour. It rotates on its axis at a speed of 1000 miles an hour at the equator. These things are hard to believe, yet careful measurements made by scientists with the help of their telescopes show that they are true. They also find that the earth's axis does not point straight "up and down" as the earth goes around the sun. It is tilted 23½ degrees.

The two movements of the earth and the tilt of the axis explain many things. You already know why we have years. A year is the length of time the earth takes to go around the sun. Day and night are caused by the earth's turning on its axis so that we are carried out into the light of the sun and then back into the

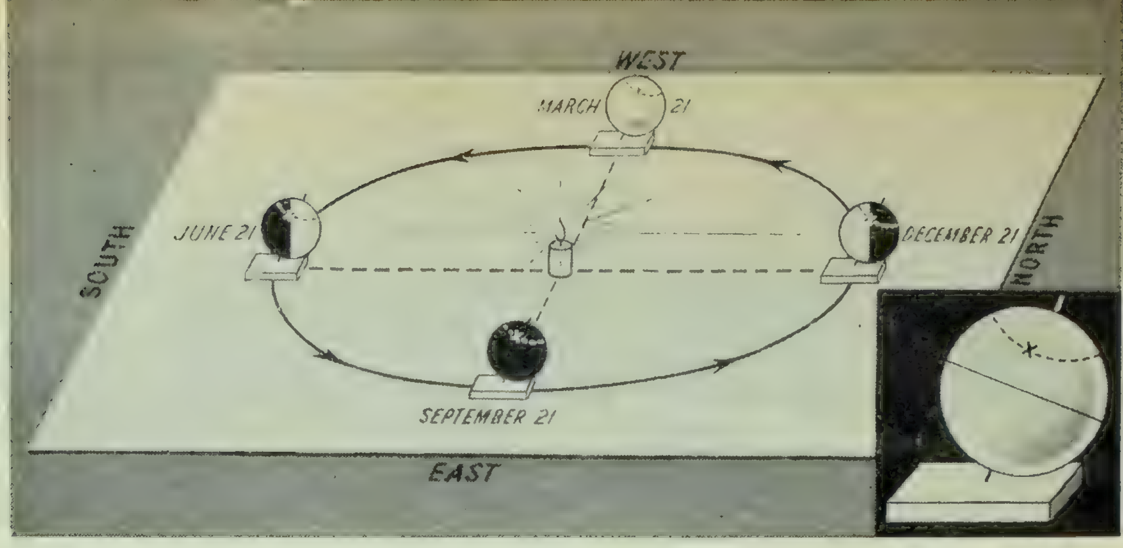


Fig. 306. Apparatus for Experiment 71. The drawing in the lower right corner shows you how to mark the latitude of the place where you live.

earth's shadow each twenty-four hours. But why are the days longer in summer than they are in winter?

WHY DO THE DAYS AND NIGHTS DIFFER IN LENGTH AT DIFFEPENT TIMES OF THE YEAR? Everyone knows that the longest days in the year come near June 21, and the shortest days near December 21. About March 21 and September 21 the lengths of the days and nights are equal. Now let us see if we can understand this change in the lengths of the days and nights.

*Experiment 71.* WHY DOES THE LENGTH OF THE DAYS AND NIGHTS CHANGE? (*a*) Push a knitting needle or wire about six inches long through a tennis ball. The tennis ball is to represent the earth. Draw a circle around the ball to represent the equator. Draw another circle to show the latitude in which you live, and place an X on it to represent your city. Make a stand for the ball (Figure 306).

Now draw a circle at least two feet in diameter upon a piece of wrapping paper. This represents the earth's path around the sun. Divide the circle into quarters, as shown in Figure 306. Write the dates of the beginnings of the four seasons. Turn the paper so that the winter position is in the north, and set a lighted candle at the centre of the circle.

Place the ball on the circle at the point marked autumn, with the needle (axis) in a perpendicular position. Observe that the light from the candle lights up the ball from pole to pole. Turn the ball on its axis. Does it still light up the ball from pole to pole? Now place the ball, in turn, at the points marked for each of the other seasons and rotate it. Does the candle always light up the ball from pole to pole? If the axis of the earth were straight up and down, would the lengths of the days and nights change?

*b*) Place the ball at the autumn position (east of the candle), with its axis at an angle of about 23 degrees from the vertical line and pointing toward the north. (This angle can be measured with

a protractor.) Rotate the ball on its axis. Does the candle light up the ball from pole to pole? Would the length of the days and nights be equal at the spot on the "earth" marked X?

c) Place the ball in the winter position, with its axis still tilted toward the north. On the circle where you live measure with a piece of string the part of the ball that is lighted. Also measure the part of the ball that is dark. Will the days be longer, shorter, or the same lengths at this season of the year?

d) Move the ball to the spring position and repeat part *b* of the experiment. Will the lengths of the days and nights be equal?

e) Move the ball to the summer position and repeat part c of the experiment. Will the days be longer, shorter, or the same lengths in the summer?

Now let us see what this experiment shows. You found that the days and nights would be the same length all year round if the axis of the earth were perpendicular to the path it takes around the sun. But you know that the days and nights are not the same length all during the year. When the earth's axis was tilted, you found that in autumn and spring the earth was lighted from pole to pole. When the earth rotated, the lengths of the days and nights were the same. In the winter, the lighted part of the earth where you live was smaller than the dark part. Therefore the days were shorter than the nights. In summer the lighted part of the earth where you live was larger than the dark part. Therefore the days were longer than the nights.

From this experiment you can see that the length of days and nights changes because of two facts: (1) the axis of the earth is tilted; (2) the earth moves around the sun.

*Self-Testing Exercises.* 1. Why are the lengths of the days and nights the same about March 21 and September 21?

2. Why are the days shorter in winter than in summer?

3. State all the things you need to know to explain why the lengths of the days and nights change during the year.

*Problems to Solve.* 1. Make a graph showing the lengths of days and nights for your locality, (*a*) on December 21 and (*b*) on June 21.

2. At Hammerfest, Norway, which is located at 71° N., the sun never sets from May 13 to July 8 and never rises from November 12 to January 23. See if you can explain why this is true.

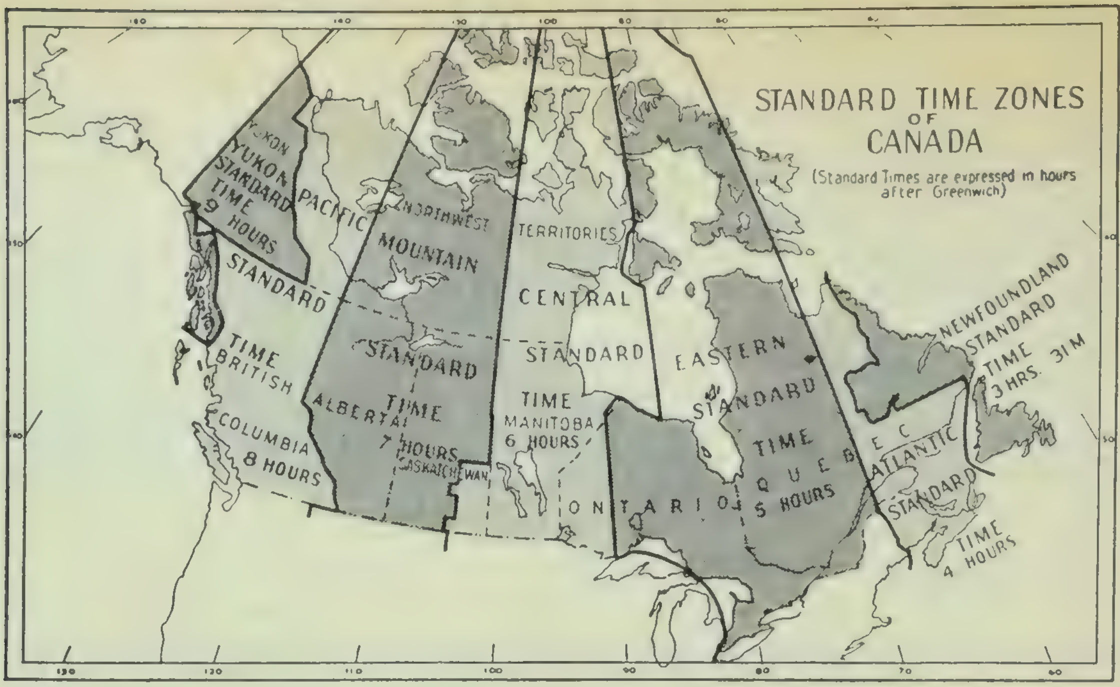


FIG. 307. Each time belt extends about 7½ degrees east and west of its meridian. This meridian is exactly 15 degrees from the meridian of the adjoining belt. The boundaries of the different belts are irregular because it was found more convenient in operating the railroads to change times at certain stations.

WHY DO WE HAVE DIFFERENT TIME IN DIFFERENT PARTS OF OUR COUNTRY? If you ever travelled across Canada, you discovered that at certain places it was necessary to change your watch. If you travel east, you set your watch an hour faster at certain places. If you travel west, you set your watch an hour slower. Probably you have noticed that a radio program scheduled at nine o'clock in Montreal comes on the air at eight o'clock if you live in Manitoba and at six o'clock if you live on the Pacific coast. Do you know why this is true and how the different times are determined?

As you watch the sun in the morning, it appears to rise in the east. Actually, of course, the earth is rotating from west to east, and, as it turns farther and farther, the sun appears higher in the sky. The circumference of the earth is about 25,000 miles at the equator. Since the earth turns once on its axis every twenty-four hours, you see that the earth is rotating at a speed of about 1000 miles an hour at the equator, or about 17 miles per minute. At the latitude of Windsor, Ontario, the earth is not so large around, and its speed of rotation is about twelve to thirteen miles a minute. This means of course that in a city about 800 miles west of Windsor the sun would rise an hour later. Between the two cities the sun would rise at about a minute later for each twelve or thirteen miles that the place was farther west of Windsor. Each place would thus have a different time by the sun.

It would, of course, be very confusing if each city had its own time. For this reason the government has adopted a *standard time* system. The sun reaches the eastern part of the continent first; so all places within one-half hour's time east and west of the 75th longitude line, or *meridian*, have *Eastern Standard Time* (Figure 307). They are in the Eastern Time Belt. Similarly, places along the 90th meridian have *Central Standard Time*; those along the 105th meridian have *Mountain Standard Time*; and those along the 120th meridian have *Pacific Standard Time*.

People who travel long distances have to set their watches back an hour whenever they cross from one time belt to another in going from east to west. Going from west to east, they set their watches forward one hour for each time belt. The man mainly responsible for the use of the standard time system throughout the world was Sir Sandford Fleming, a Canadian engineer.

*Self-Testing Exercises.* 1. Why do different places have different time by the sun?

2. What is the standard time system?

3. Why was the standard time system adopted in Canada?

4. How many time belts are there in Canada? In which one do you live?

WHY DO WE HAVE SEASONS? If someone asked you why the days are warmer in summer than in winter, your first answer would probably be, "Because the days are longer in summer." Your answer would be partly correct, because the days are longer in summer than in winter, and the earth therefore receives more heat during the longer hours of sunlight. But this is not the only reason why summer days are warmer. There are other conditions that help make summer warmer than winter. The following experiments will help you see some of the other conditions that cause the seasons.

*Experiment 72.* HOW DOES THE ANGLE OF THE SUN'S RAYS CHANGE FROM DAY TO DAY? Get a piece of cardboard to put on a window-pane in your schoolroom and cut a four-inch square from the centre of it. Fix the cardboard over a window-pane where the sun will shine through the opening. Place a piece of paper upon a table-top or

other flat surface in the spot of sunlight and draw the outline of the bright area (Figure 308). Write the date and exact time upon this sheet of paper.

Repeat the experiment again a week later. Be sure to do the experiment at exactly the same time of day and place the paper in the same position as before. Do the experiment several more times at intervals of a week. Compare the shapes of the lighted areas. Do the shapes appear to be changing? Does the lighted spot get nearer to, or farther from, the window? From this experiment, can you say that the angle at which the sun's rays strike the earth changes from time to time?

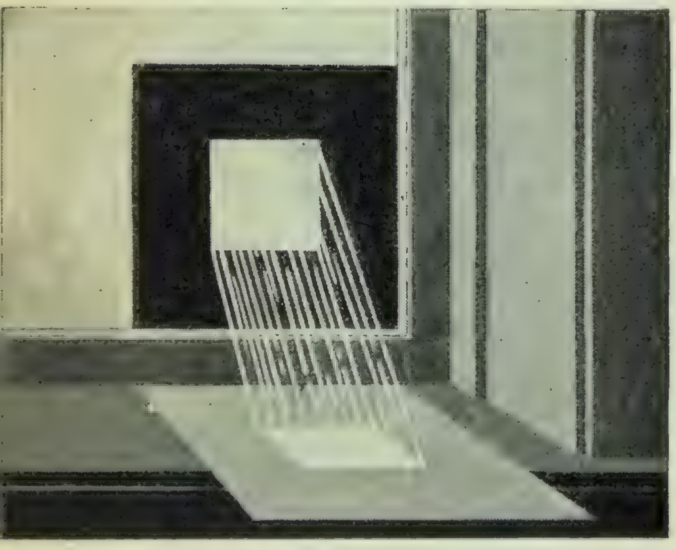

FIG. 308. Apparatus for Experiment 72

*Experiment* 73. HOW DOES THE ANGLE OF THE SUN'S RAYS AFFECT THE AMOUNT OF HEAT THE EARTH GETS? Fill two cardboard boxes with sand or dry soil as shown in Figure 309. Lay thermometers on the boxes, with the bulbs buried in the sand.

Place one box, as shown in *A* of the figure, so that the sun's rays will fall upon it vertically, that is, at an angle of ninety degrees. Arrange the other box with sand and thermometer and place it on two small blocks, as shown in *B* of Figure 309, so that the sun's rays will fall upon the sand and the thermometer at an angle of about forty-five degrees.

Allow the sunlight to shine upon both boxes for about twelve minutes. Record the temperature of the sand on both boards. Are direct or slanting rays of the sun hotter?

You have probably observed that the sun gets almost straight overhead at noon in summer. In winter, however, the sun at noon is scarcely half-way up to that point. From Experiment 71 you will remember that the upper half of the earth (where we live) is slanted toward the sun in summer. In winter the opposite is true: The axis of the upper half of the earth is slanted away from the sun. This slant of the earth's axis causes the sun's rays to strike the earth at different angles during different seasons of the year. Vertical rays in summer, when the sun is almost directly overhead, give a greater amount of light and heat to the earth. Slanting rays in winter give less light and heat.

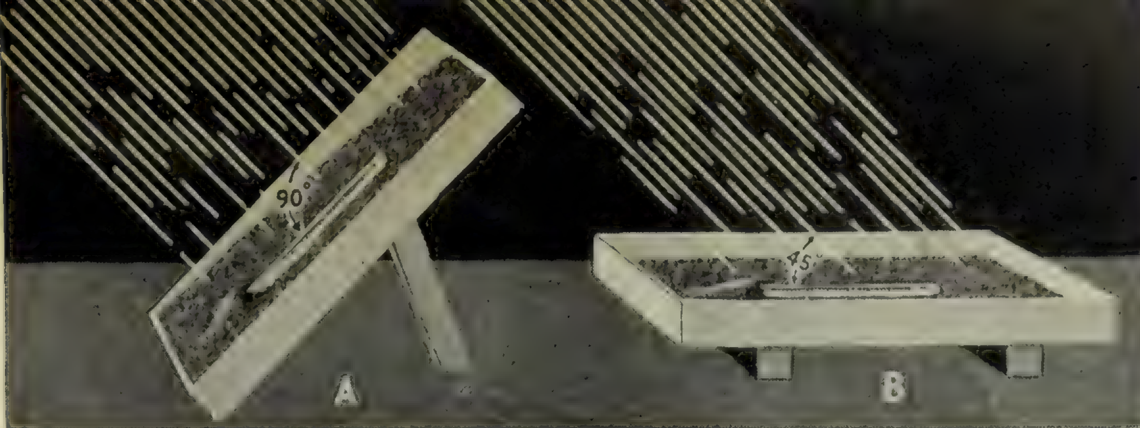


FIG. 309. Apparatus for Experiment 73

If you compared the amounts of light and heat received by a square foot of the earth during the same hour in winter and summer, say from one to two o'clock in the afternoon of an average day, you would find that the amount of heat and light received would be much greater in summer. You learned from your experiments that the more nearly vertical the sun's rays are when they strike the earth's surface, the smaller amount of surface they cover. When the same amount of radiant energy is spread over a smaller surface, the amount of heat received by that surface will be greater.

As you have learned, in winter the sun's rays strike the earth at a much greater angle than in summer. This affects the temperature of the earth in another way. When the sun's rays strike almost vertically, they have much less atmosphere to pass through than when they strike the earth at a greater angle. Dust particles or particles of other substances in the air help stop or scatter the sun's rays. So, when these rays have a smaller amount of atmosphere to pass through, the earth receives more heat.

*Self-Testing Exercises.* 1. Close your book and give three reasons why summer is warmer than winter.

2. Close your book and draw a diagram that shows why the sun's rays shine more nearly straight down on you in the summertime. First, draw a circle to represent the earth. Add marks for the North and South Poles. Put an X on the circumference about where you live. Then add the sun and its rays.

*Problems to Solve.* 1. Use a diagram like the one for Self-Testing Exercise 2 to show why people on the southern half of the earth have warm weather at Christmas time.

2. Do people who live at the equator have summer and winter as we do? Explain.

3. How would our seasons be different if the axis of the earth were not inclined?

## 4. How do astronomers learn about the heavenly bodies?

SCIENTISTS WHO WORK WITH THINGS ON THE EARTH can handle the materials they are studying. They can feel and weigh and measure them. They can put samples into test-tubes and find what elements and compounds are present. But astronomers cannot do that. All they have to work with is the light that comes from the heavenly bodies. Yet astronomers are able to tell us that what appears to be a mere point of light in the night sky is really two great suns fifty light-years away, revolving around each other and at the same time travelling away from the earth at a rate of twenty-five miles a second. The astronomers can also tell us what elements these suns and other suns are made of. How can so much be learned from such a tiny bit of light?

HOW DO TELESCOPES HELP ASTRONOMERS? Telescopes do two things that are helpful in studying the stars. They magnify such objects as the moon or a planet so that these heavenly bodies appear to be larger and nearer than when we look at them without an instrument. To make a magnified moon bright enough to study with care, the telescope must also gather a great deal more light than can fall on the pupil of a person's unaided eye. However, even the most powerful telescopes show all stars as points of light. The only thing a telescope can do is make them seem brighter by gathering a great deal of light and concentrating it at one point. In Unit 18 you will learn how telescopes are made so that they can do these things.

Astronomers use a telescope to take pictures by removing the eyepiece and putting a photographic film where the *image*, or picture, is made by the large lens. If the image is kept in exactly the same place for a long time, the photograph that is made shows many stars that cannot be seen by looking through the telescope. Some star pictures have been exposed night after night until the starlight has shone on the films for twenty-five hours. Two- and three-hour exposures are quite common.

HOW DO ASTRONOMERS MEASURE DISTANCES? We have already learned that the early astronomers invented instruments for sighting stars and measuring their positions. Methods of

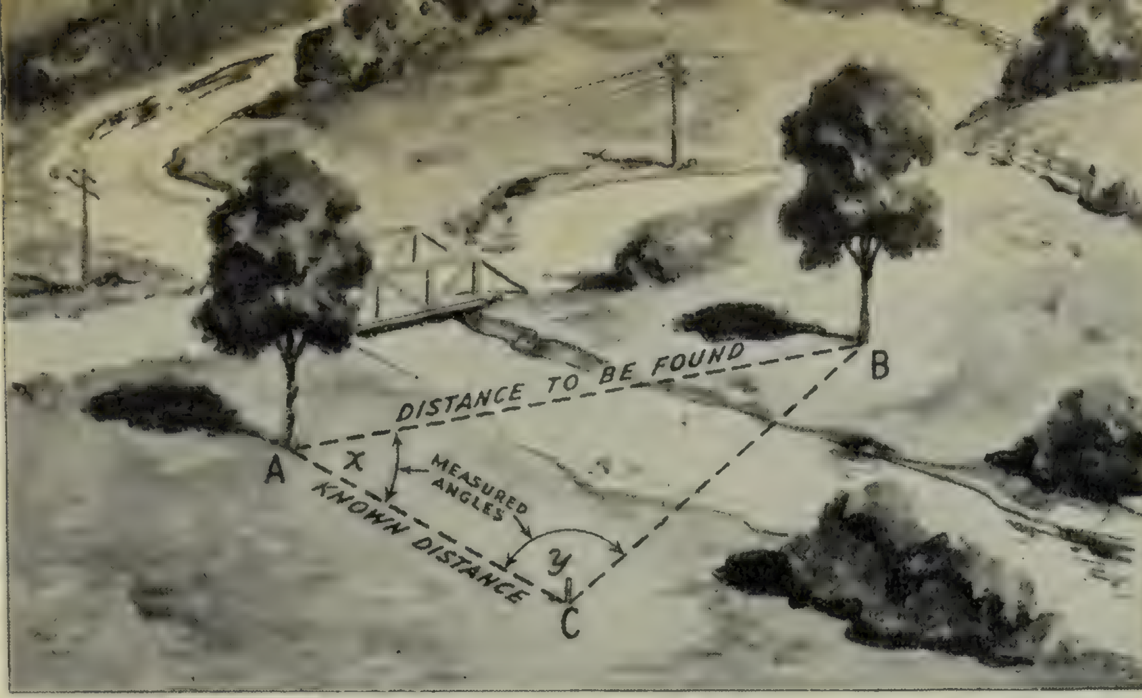


FIG. 310. A surveyor can find the distance between two places by measuring angles and solving a mathematical problem.

measuring angles are now so accurate that an astronomer in Winnipeg, watching a light as far away as Toronto, could measure how far it is moved sidewise and not make a mistake of more than three-fourths of an inch.

To measure distances, astronomers follow the plan used by surveyors when they measure the distance to some object on the opposite side of a river. If the surveyor wishes to know how far tree B is from tree A (Figure 310), he sets a stake at C. With his instruments he measures the angle at x, the angle at y, and the distance from tree A to the stake, C. Then by solving a mathematical problem he can find the distance between A and B. In a similar way, two astronomers located at different points may sight a planet at the same time. Then, by knowing the position of the planet as seen from each telescope and the distance between telescopes, they can calculate the distance to the planet.

When astronomers began to measure the distances to stars, they had to make a change in their method. Most stars are so far away that no difference in the angle can be found from different points on the earth's surface. Astronomers found, however, that if they sight these stars at one time and then sight them again six months later, a difference in the angle is obtained. During the six months the earth travels half-way around the sun. It is then 186,000,000 miles away from the place it was six months before. This gives the astronomers a triangle with one side 186,000,000 miles long. By this method the distance to stars that are not more than 300 light-years from the earth (about 1,761,000,000,000,000 miles) can be measured fairly accurately.

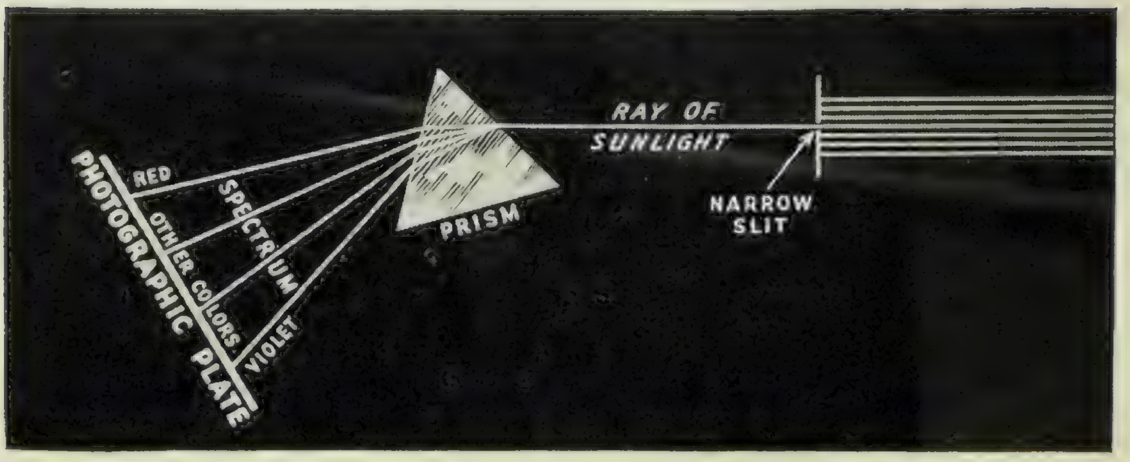


FIG. 311. In a spectrograph a prism bends each color in a ray of light a different amount and thus separates it from the other colors. In real spectrographs several lenses are used to make the lines in the spectrum distinct.

Most stars are farther away than 300 light-years. They are so far away that they seem to stand still as the earth swings around the sun. To estimate the distance to these farther stars and to measure the diameters of stars, astronomers must use methods that we cannot explain to you now.

HOW CAN ASTRONOMERS TELL WHAT ELEMENTS ARE IN THE SUN AND THE STARS? Have you ever seen a ray of sunlight shining through a triangular bar of glass or through the corner of a rectangular aquarium? If so, you have seen how the white light of the sun is spread out into a band of rainbow colors. This band of colors is called a *spectrum*. It shows that sunlight is really a mixture of many different colors of light.

The triangular piece of glass used to spread out a ray of light in this way is one kind of *prism*. By sending a ray of light through a narrow slit, a prism, and some lenses, scientists can make a very perfect separation of all the colors of light in a mixture. An instrument that separates the colors of light in this way is called a *spectroscope* (or *spectrograph*, if it takes a picture of the spectrum). Astronomers use spectroscopes and spectrographs to learn what kinds of materials the sun and stars are made of. How can they do this?

To learn how a spectroscope can analyze starlight, you need to know a few new facts about the way elements behave on the earth. When some substance containing the element sodium is vaporized in a flame, it gives a very bright yellow light. When

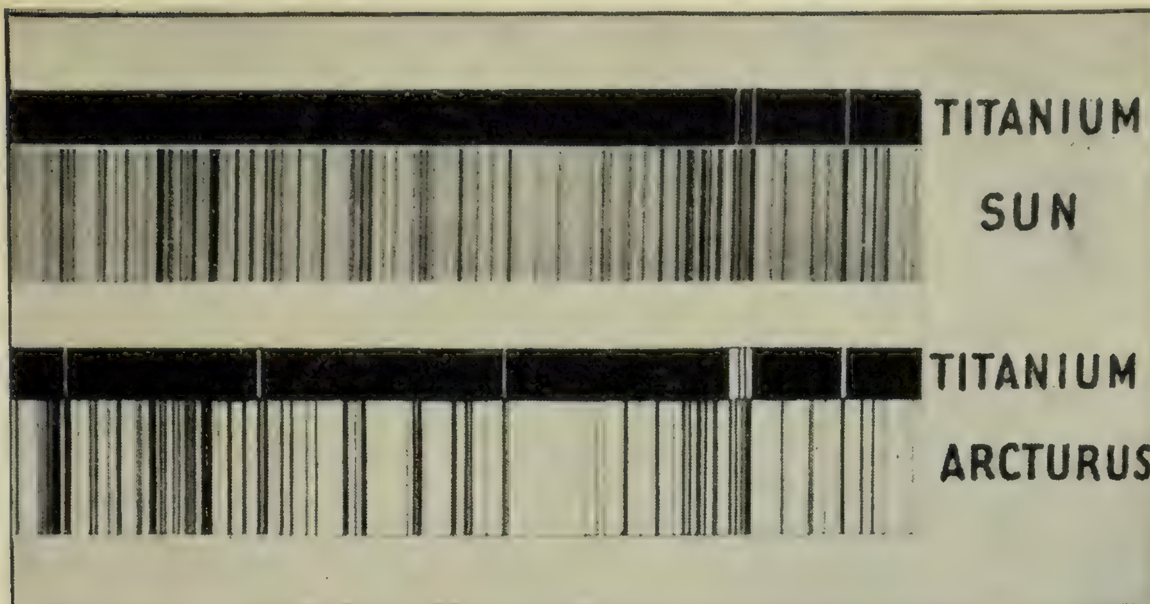


FIG. 312. Part of the spectrum of the sun and Arcturus are compared with lines from the light of the element titanium in the laboratory. Notice how each bright line from the element is matched by a dark line in the spectrum. This tells scientists that gaseous titanium is found in the atmosphere of both the sun and Arcturus. The other dark lines are from other elements. (Yerkes Observatory photo)

this light is sent through a good spectroscope, two yellow lines can be seen very close together in a certain place in the instrument. No other element gives two lines in exactly this position. When a scientist finds these yellow lines in the spectrum of any substance, he knows that the substance contains sodium.

Each element has its own peculiar set of lines; and usually there are many lines, rather than a few. Iron, for instance, produces hundreds of lines. By vaporizing any unknown substance and causing it to give out light, either in a flame or by means of electricity, scientists can tell just which elements are present in a substance. The material in the sun and in most stars is glowing gas. Thus each element in these heavenly bodies gives out its own particular colors of light. When they reach us, they are mixed up. By using the spectroscope, astronomers can separate the different colors and find the lines that come from the different elements in the sun and stars. The light from nearly sixty elements has been found in sunlight. Among these are such common elements as calcium, hydrogen, iron, magnesium, nitrogen, oxygen, silicon, and sodium. Lines from an unknown element, that later was named helium ("sun element"), were

found in the sunlight more than twenty-five years before helium was discovered on the earth.

*Self-Testing Exercises.* 1. What kinds of messages do astronomers receive from the stars?

2. Why are telescopes the most important instruments used by modern astronomers?

3. How do astronomers measure the distance to a body in the solar system? To one of the nearer stars?

4. What differences do scientists find in the light from different elements when the elements are very hot?

5. What does a spectroscope tell scientists about stars? How does it work?

*Problems to Solve.* 1. What was probably the first kind of astronomical instrument?

2. Give some of the ways in which mathematics is useful to an astronomer.

3. Why are astronomers unable to use the triangle method in measuring distances to the farthest visible stars?

## Looking Back at Unit 13

1. This unit emphasizes a number of important scientific ideas. You should have most of them clearly in mind. Without your book try to write all the "big ideas" of the unit in a list. The sub-problems of each problem will help you see what these big ideas are. State each one in a complete sentence, thus:

*a*) The sun is the centre of the solar system.

*b*) All the bodies in the solar system revolve around the sun.

2. In your list for Exercise 1 put a star in front of the ideas that seem most interesting and important to you.

3. After your study of Unit 13 you should understand the following words. Show in some way that you understand them. You can show your understanding in any one of several ways: (*a*) by giving a definition of each one in your own words, (*b*) by using the word in a sentence, (*c*) by giving an example, (*d*) by telling something about each one.

| | | | |
|---|---|---|---|
| *star* | *galaxy* | *light-year* | *satellite* |
| *comet* | *nebula* | *meridian* | *constellation* |
| *orbit* | *eclipse* | *meteorite* | *solar system* |
| *planet* | *universe* | *astrologer* | *spectrum* |
| *meteor* | *sun-spot* | *astronomy* | *standard time* |

## Additional Exercises

1. The longest and shortest days occur about June 21 and December 21. However, the warmest and coldest weather do not usually come until about a month after these dates. Explain why.

2. Make a booklet telling of people's early beliefs about astronomy.

3. Make a booklet of important astronomers, telling about their lives and their work. Include such men as Galileo, Kepler, and Copernicus.

4. Make a North-Star finder like the one shown in Figure 313. On some clear, dark night, go into the open where there are no trees or buildings to obscure your view. Push the sharpened end of a broomstick firmly into the ground and turn the pointer north by means of the compass.

By means of the protractor set the pointer to correspond with the number of degrees of latitude where you live. Sight down the pointer, and you should be able to find the North Star.

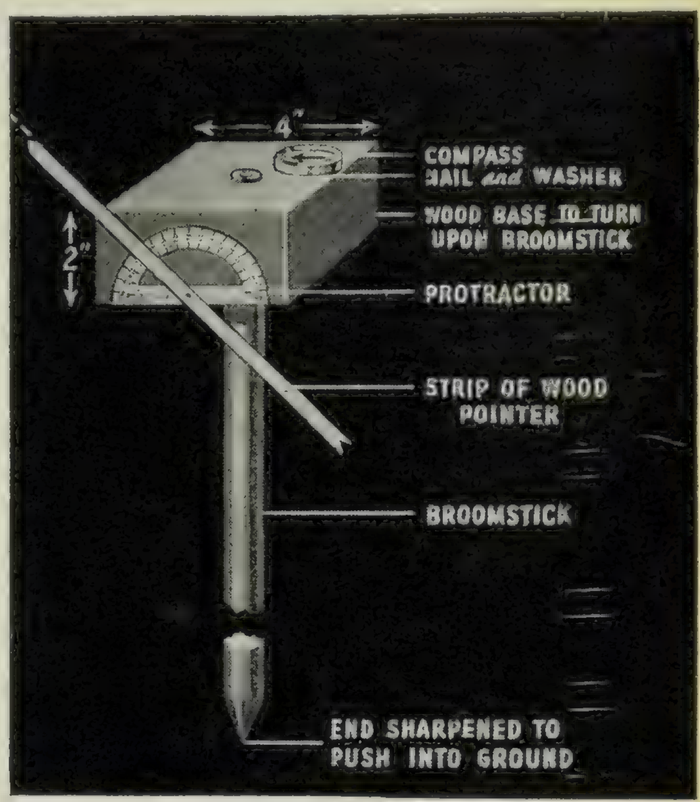


FIG. 313. Apparatus for Additional Exercise 4

5. Here is an easy way to get an idea of how far the planets are spaced from the sun. Tie one end of a large ball of wrapping twine to a post on the playground. Let the post represent the sun.

Using a space-scale of one inch to 36,000,000 miles, refer to the table on page 420 and figure out the distances each planet would be from the sun according to your scale. For example, if one inch equals 36,000,000 miles on your scale, Mercury would be one inch from the post, which represents the sun. Make a loop in the cord at this place and tie a paper clip here. Place a card marked "Mercury" in the paper clip.

Do the same for each of the other planets. You may be very much surprised at the results of the exercise.

6. Make a sun-dial and use it for telling sun time, or solar time. Fasten a square or round board firmly to the top of a strong post. Be sure it is level. Fasten a large spike nail or heavy wire vertically in the board near its centre.

By using a compass or "sighting" at the North Star at night, draw a line on the board straight north of the wire. On a sunny day set

your watch at twelve o'clock noon, when the shadow of the wire points straight north. Then make marks where the shadow falls at the other hours of the day.

7. Read in reference books about the great telescopes of the world.

8. If you wish to do some further work in astronomy, obtain an astrolabe (a kind of star-finder) made by the Geographic Press of Columbia University, New York City. This device will enable you to locate stars easily and to learn many other things about the movements of heavenly bodies.

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Clouds of dust and sheets of flame pour from the world's newest volcano, Paricutin, which only a few years ago burst from the earth in a Mexican farmer's cornfield. Its cone of ash and rock is now more than 1200 feet high and still growing. A village several miles away has been buried, and much good farm land has been ruined. Almost from its beginning scientists have been able to study this volcano and observe the changes that it made. In this unit you will learn about the forces that are constantly changing the earth's surface. (W. F. Foshag photo)

# UNIT 14

# How Does the Earth's Surface Change?

## Looking Ahead to Unit 14

A GROUP OF MEN were sitting in front of a store in a small town. It was a hot day in summer, and everything seemed very dull and uninteresting. Finally a young man said "I wish something would happen around here. Nothing ever does. If I could come back to this place a thousand years from now, I believe I'd still recognize it. Not a thing would be changed."

"I'm not so sure of that," said an old man sitting near. "I've been here for sixty years, and I've seen a great many changes in this short time. Even the land seems different! When I came here as a boy in 1876, the place was mostly in woods; and in the fields that were cleared the soil was rich and black. No one ever thought of fertilizing his crops. Later, most of the trees were cleared away, and the drainage canal was dug. Soon the surface soil began to wash away, and gullies began to form. One of the finest houses in the village stood where Black Creek now runs through the western part of town."

"Well, that is hard to believe," said the young man. "Black Creek is about fifteen feet deep."

"But it's true," was the old man's reply, "and a great many other changes have taken place. You know that big swamp just below town? That swamp was once a lake. Now it has filled up until it is only a foot or two deep. So many changes have taken place since I've been here that I'd not be able to recognize it as the same place."

People often think, as the young man did, that the earth does not change. But scientists can easily prove to you that the surface of the earth is really changing all the time. Some changes happen quickly. For example, in a few hours or days a great flood may change the course of a river. Or the flood may deepen the chan-

FIG. 314. In 1926 Lake Como, Minnesota, was as you see it here—a beautiful lake around which a popular summer resort grew up. Just ten years later it looked as you see it in Figure 315. See if you can think of some reasons for this rapid change before you read the legend beneath Figure 315. (Soil Conservation Service photo)

nel of the river in one place and leave sand-bars where there were none before. An earthquake may make great changes in a few seconds. About a hundred years ago a great earthquake was felt in western Tennessee. Afterwards it was discovered that an area of land eighteen miles long had been lowered, and water had poured in to form a lake.

Other changes take place so slowly that even the *geologists* (scientists who study rocks) are not sure that these changes are going on. For example, geologists are fairly sure that a range of new mountains is rising in the western part of the United States, but several generations may come and go before we can be certain that this change is taking place. Have you ever wondered how the soil and rock, the valleys and lakes, and the plains or mountains near your home were formed? In this unit you will learn about the kinds of changes that have been going on in your own neighborhood for many millions of years.

## ¶ 1. How is the surface of the earth worn down?

HOW ARE ROCKS CHANGED INTO SOIL? What is the earth's surface made of where you live? Is it nearly all soil or nearly all rock? For almost everyone the answer to that question is "Soil." The parts of the earth where people live must have soil

Fig. 315. Here you see Lake Como as a swamp through which a small stream moves slowly. This may be explained by the fact that soil which is carried away from one place by water must be deposited as sediment in another place. Thus, soil that has been carried away from a hillside may pour into a lake in such quantities that the lake is filled up with it, which is what happened in the case of Lake Como. (Soil Conservation Service photo)

to grow plants for food. But if you dig down into that soil far enough, you will always come to bed-rock. Scientists tell us that everywhere the surface of the earth was once rock of some kind. How can hard rock change into soil? That stone door-step of your home hasn't changed a bit since you were old enough to notice it! And the stone walk in grandfather's garden has been there since he was a little boy. The stones that you know do not seem to be changing. But you remember that these changes take a long, long time! And there have been millions of years for rocks to change. Let us see if we can find some rock that nature has been changing.

*Experiment* 74. HOW DOES STONE THAT HAS BEEN EXPOSED TO WATER AND AIR DIFFER FROM PROTECTED STONE? Get a number of different stones from the soil, from streams, and from other places near where you live. Look especially for some that seem to be soft and "crumbly" on the outside. You may even wish to crack a corner off one of the pieces of an old stone walk or wall if no one will care.

With a knife try to scratch the outside of one of the rocks you have collected. Notice its color and hardness. Then lay it on a large rock or piece of metal and break it with a hammer. Test the centre of the broken stone as you did the outside. Is the centre like the outside, or has the outside been changed in some way by its exposure

to water and air? Examine other pieces of stone in the same way. Have some changed more than others? If so, can you think of reasons for the differences?

Many pieces of rock have a different color and are softer on the outside than in the centre. The outer parts of some can be flaked or scraped off very easily. Of course, there are great differences, because the rocks are of different kinds, and some have been exposed to the weather longer than others. The changes that you have noticed are mostly chemical changes. They are caused by water, carbon dioxide, and oxygen. Most kinds of rocks are formed deep in the earth. As soon as they are exposed to moisture and air, chemical changes begin to destroy them.

Most of the chemical substances or minerals in rocks are changed into new materials. *Quartz* is one substance that is changed very little by chemical action. Quartz is a mineral found in many rocks. It is a chemical compound composed of one part of the element silicon and two parts of the element oxygen. The chemical formula is $SiO_2$. Quartz is so hard that a steel knife will not scratch it. When rocks containing quartz are gradually destroyed, the quartz is broken into smaller and smaller pieces. It is finally left as *sand*. Rocks contain many minerals besides quartz. Almost all of these other minerals form very fine mud which we call *clay* when the rocks are broken up and destroyed by nature. The sand and clay in our soil, therefore, come from the destruction of rocks. The kind of soil found in any place will depend on the kinds of rocks that were changed into the soil and upon the amount of *humus*, the brown or black decayed plant and animal material, that has been formed and mixed with the sand and clay.

The chemical changes that destroy rock are caused by the action of air, rain, and sun; therefore they are often spoken of by scientists as the *weathering* of the rock. But chemical changes are only part of the changes that after a time destroy all rock that is exposed to the air. Look at the picture on page 454. Notice the pile of broken rock at the bottom of the solid rock cliff. Notice also how the rock of the cliff is split. Such cliffs are very common. An experiment will show you one way in which rock is broken into pieces.

Fig. 316. This cliff of solid rock is being broken up gradually. Did you ever see a cliff like this with broken rock at the bottom? How did the rock become broken off into smaller pieces?

*Experiment* 75. HOW DO EXPANSION AND CONTRACTION BREAK ROCKS? (*a*) Obtain a strip of ordinary window glass about six inches long and three inches wide. Almost any piece of broken glass several inches long will do. Hold one end of the glass in the flame of a gas-burner for a few moments. What happens?

*b*) Heat a piece of glass tubing until it is quite hot. Then plunge it into some water. What happens to the glass?

The glass broke in the experiment because not all parts of it were heated and cooled equally. One part of the window glass became hot and expanded more rapidly than other parts. This made the glass break. The glass tube was cooled on the outside by the water, but the inside stayed warm. Therefore, as the glass cooled, the outside contracted faster than the inside, and cracks were made all through the tube. Some kinds of rock are cracked in much the same way. When they are heated on the outside by the bright sunlight, the outer part expands faster than the inside, and pieces break off. In other rocks very tiny cracks appear because of heating and cooling.

Cracks in rocks allow both water and air to enter. As you have learned, water and air cause chemical changes that soften the rock. Because of these cracks, weathering goes on inside the rock as well as on the outside. When water runs into a crack and freezes, it also makes the crack wider. An experiment will show you how this happens.

*Experiment 76.* HOW DOES WATER ACT WHEN IT FREEZES? Fill a bottle completely full of water. Do not allow any bubbles to remain. Wire a stopper in the bottle tightly or tighten the screw cap as much as you can. Put the bottle in the freezing compartment of an electric refrigerator, set it outdoors on a cold night, or bury it in a mixture of three parts of crushed ice with one part of salt. What happens to the bottle when the water freezes?

From this experiment you can see how water in rocks expands with a tremendous force when it freezes. Thus the freezing of water that has trickled into the cracks in rocks helps break the rocks into smaller pieces.

The third way in which rocks are broken up is by plants. Plants send their roots into the cracks in rocks. Then, as the roots grow, they force the rocks apart and often break them into smaller pieces. Plants and animals also help in the chemical weathering of rock. Growing roots give out chemical compounds that dissolve away the surface of some kinds of rock. Chemicals from decaying plants also soften rocks. Ants, earthworms, and larger animals that burrow in the soil allow water and air to get down into the soil around rocks. The fourth way in which rocks are broken into pieces is by the action of moving water, wind, and ice, as you will learn later in this unit.

*Self-Testing Exercises.* 1. How can you tell when a rock has been changed by chemical weathering?

2. How can changes of temperature cause rocks to break?

3. Name three ways in which plants help in the formation of soil. Explain each one briefly.

4. What are three important materials found in soil?

5. What determines the kind of soil found in any particular place?

*Problems to Solve.* 1. List the ways in which a piece of rock you find in the soil may be different from a piece of the same kind of rock that has just been taken from a stone quarry.

2. Refer to the Science Words that begin on page 715 and find out what kind of soil *loam* is.

3. Why are we sure that rocks change into soil, even though we cannot notice the rocks changing from year to year?

4. Write a brief description of the earth as it might be if rocks could not be broken up or changed into soil.

5. Read in reference books about quartz and other common minerals, such as feldspar and mica. Find how each one may be recognized.

6. Why is it possible to find several kinds of soil in one locality?

7. What is the main kind of soil found in your neighborhood? Find out all you can about it.

8. Collect different kinds of pebbles from as many different places as you can. Try to decide how each pebble has been shaped. That is, was it shaped by running water, by waves, by a glacier, or by weathering?

9. Which ways of changing rock to soil have been most important in your locality?

10. Weathering of rock is more rapid where the weathered part is removed from the rock as fast as it is weathered. Explain why.

How does moving water wear away the land? We think of the Panama Canal as one of the great engineering feats of the world. Construction engineers spent ten years moving 240,000,000 cubic yards of material to make the canal. That amount of material would fill all the freight cars in Canada several times! Yet, impossible as it may seem, in nine months' time the Mississippi River alone carries more material into the Gulf of Mexico! We use wagons, railway trains, trucks, automobiles, and aeroplanes to transport things. Nature uses only water, wind, and ice. And the force that moves all three of these is gravity!

What are some of the rules that water follows in carrying materials? One of the simplest rules is the result of the pull of gravity. Water, as it flows over the surface of the earth or through spaces within the earth, moves downward. Therefore it is a general rule that *materials carried by water are moved to lower places.* A second rule is almost as simple as the first: *The amount of material that water can carry depends on how fast the water is moving.* The faster water runs, the more material it can carry. It may even roll large stones. Whenever water slows down, it must drop part of the load it has picked up. A third rule is closely tied up with the second rule: *Water sorts the materials it carries.* It sorts the materials into large and small pieces because it can carry large pieces only when it is moving rapidly. When it begins to slow down, it first drops the largest pieces. A little

FIG. 317. Each year new land is made around the edges of these islands in the lower part of the Mississippi River. The land is made from the soil that the water carries down the river and drops on the islands as the water moves more slowly because the land becomes more level. (Chicago Aerial Survey Company photo)

farther along, as it moves more slowly, it drops smaller pieces. The fine mud will not settle until the water has been perfectly quiet for a time. Materials that are being carried by the water are said to be *suspended* in the water. Or they are said to be *in suspension*. They are called sediment.

Running water also carries materials that it has dissolved. Rainwater that falls on the soil dissolves some kinds of minerals from soil and rock and carries the minerals away into near-by streams. As you know, the particles of dissolved materials are too small to be seen, and they cannot be filtered from the water. Thus, water that has been filtered through much sand and soil may be perfectly clear and yet be carrying minerals in solution. The amount of minerals carried in solution at any time is usually not large, but over a long period of years water will dissolve and carry away great amounts.

But, as you know, not all the rain water flows off into streams. Some of it soaks into the soil and stays there for long periods of time. As this ground water moves slowly down through the soil and rocks, it dissolves many substances. Some of the minerals will dissolve in pure water. Others will not dissolve in water alone, but they will dissolve in water that contains some other substance, such as carbon dioxide. For example, limestone is almost entirely a white mineral called calcium carbonate ($CaCO_3$). This mineral does not dissolve easily in pure water. But carbon

dioxide dissolved in the water changes the calcium carbonate into another compound, called calcium bicarbonate, that dissolves rather easily. The carbon dioxide to cause this change comes from the roots of plants and from decaying plants in the soil.

Before you go further in your study of how the high parts of the earth are worn down, you will need to have clearly in mind the meaning of a word often used by geologists. This word is *erosion*. You have learned that rock is gradually destroyed by weathering; that is, water, ice, and wind slowly wear away the hardest of rocks. You have also learned that water picks up materials from the highlands and carries them with it on its way to the sea. All this wearing down and carrying away of the rocks and soil is called erosion. As you will soon see, erosion is very important to all of us.

Almost everyone carries in his mind the picture of some great river valley that he has seen or of some small stream valley that he has explored. Many years ago people had queer explanations of how these valleys were formed. Some believed that they were made by earthquakes that opened cracks in the earth. They thought that after the valleys had been formed, water collected in them to make streams. Gradually scientists came to see that the stream that flows in almost every valley has itself dug the valley. They learned how to read the history of valleys, and they discovered many strange and interesting facts about them.

FIG. 318. A young valley is deep and narrow at the bottom. At the top, where the banks are washed away, it is wider. (H. Armstrong Roberts photo)

A valley begins as a narrow groove in the earth. If the stream runs rapidly, the water cuts deeper and deeper. At first the tiny streamlet can carry with it only the fine soil and very small particles of rock. As more and more water joins the stream, larger pieces and more of them can be carried or rolled along. As they move, they are jostled together

FIG. 319. Gradually the rough places and the steep sides of a young valley are worn away by the rains and the streams until it becomes a wide, gentle valley. (H. Armstrong Roberts photo)

and worn smaller as they rub and bang against each other. The sharp pieces carried by the water are used as tools to gouge out and wear away the bed-rock over which the water runs. So long as the stream is cutting deeper into the earth, its valley remains narrow with steep sides. Usually we can say that it is a V-shaped valley, and it is called a *young valley*.

Later the stream stops cutting downward so rapidly because the valley becomes more nearly level, and the water flows more slowly. The water then begins to swing from side to side in the valley as it moves along. This cuts away the banks and widens the bottom, or *floor*, of the valley. Such a valley has a U shape and is called a *mature valley*. But the water does not stop digging even though the valley has become mature. The water of the stream will continue to widen the valley and carry away material until the slope of its sides becomes very gentle. By that time the water runs so slowly that it cannot carry much sand, clay, or other materials. A wide valley with very gentle slopes is known as an *old valley*.

The history of a valley seems quite simple. But do not expect to see some young valley change into a mature one in a few years, or a mature valley become an old one during your lifetime. These changes take hundreds or thousands of years. However, you can see how the valley of a small stream develops. First, go up to the source of the stream. There you will probably find a small, steep-sided ditch, or gully. By following the stream downward, you

can see how the other parts of the valley become wider and wider, with the sides less and less steep.

In another way the action of water has also formed the great caverns that excite our wonder. Such caves are found only in regions where the rock underneath the surface is limestone. As you have already learned, water containing carbon dioxide in solution can dissolve the calcium carbonate of which limestone is made. Water from the surface of the land seeps down through tiny crevices in the rock and begins to dissolve and carry away the stone. The opening gets larger and larger until a cave is formed. Through millions of years such great caverns as Mammoth Cave in Kentucky, Luray Caverns in Virginia, and the Carlsbad Caverns in New Mexico have been produced. Sometimes the water dissolves out a funnel-shaped pit in the rock, or the roof of a cave falls in. The soil above these holes settles, and a low place, called a *sink hole*, in the ground is formed.

*Self-Testing Exercises.* 1. State and explain three simple rules that water follows in moving materials.

2. Name two ways in which water carries materials. Give an example of each way.

3. Limestone is made almost entirely of calcium carbonate, which will not dissolve in pure water. Why is ground water able to dissolve some of the calcium carbonate?

4. How are valleys usually formed?

5. How can you tell the difference between a young valley and a mature one? Between a mature valley and an old one?

6. How do waves carry on erosion?

7. Explain how caves are formed.

*Problems to Solve.* 1. Where in your neighborhood are materials carried away during a heavy rain?

2. One boy who explored several streams in a hilly region noticed that there was a deep place in the stream bed below each waterfall. Which rule of transportation by water explains how this hole was formed?

3. Imagine that you can go to the source of some stream at the head of a young valley and travel in a few minutes to the ocean through older and older parts of the valley. Tell how the valley would change and what special features you could see as you went along.

FIG. 320. Strange stories are told of how huge moving sand hills have been known to cover up roads, trees, and homes and uncover them years later. Sometimes in desert regions ancient cities have been found covered by sand. (H. Armstrong Roberts photo)

4. Are the valleys in your locality young, mature, or old? Or are all types found there? Name examples and give reasons for your answer to this problem.

HOW DOES MOVING AIR WEAR AWAY THE LAND? Have you heard of the terrible dust storms that swept over some parts of the continent a few years ago? Great clouds of dust formed in the West and were blown across the country and out over the Atlantic Ocean. In some eastern sections there was at times so much dust in the air that the rain-water was muddy. In February, 1934, a queer brown snow fell in New England. Chemists found that it was brown with a kind of soil that is found in Oklahoma, Texas, and Kansas. That single "snow-storm" dropped over thirty pounds of western soil on each acre of a large part of New England. The places where this dust came from became almost a desert. Millions of tons of the farmers' richest soil were lifted high in the air by strong winds and carried miles and miles across the country.

Under suitable conditions moving air or wind plays a very noticeable part in the erosion of the land. Dry dust on exposed places is picked up and carried for long distances. Sand, too, is moved, usually by being blown along the surface. When rocks are exposed to the currents of air carrying sand, they are worn away and sculptured into strange forms. The effects of the winds are more noticeable in dry regions than in moist regions. Moisture holds the soil together and permits plants to grow. The plants protect the surface from the wind. Their roots hold the soil, and

their stems and leaves shade the soil, thus keeping the moisture from evaporating too rapidly. In connection with wind erosion you should remember, too, that the wind is really responsible for the waves that wear away the shores of lakes and oceans.

*Self-Testing Exercises.* 1. What are the two most important causes of the dust storms that did so much damage in western Kansas a few years ago?

2. Explain how gravity is really the cause of erosion by wind. (Think about why winds blow.)

HOW DO GLACIERS WEAR DOWN THE EARTH'S SURFACE? When scientists studied the land in Canada and the northern part of the United States, they discovered a number of surprising facts. Scattered over the country north of the Ohio and the Missouri Rivers, from Nova Scotia to the mountains of the West, were stones that were different from the rock under the soil. Many different kinds of rock were found all mixed up together. Further exploration showed that the bed-rock like these stones could only be found hundreds of miles to the north. The stones must, then, have come from the north.

Many of the stones were mixed with sand and clay-like material in an unsorted mass. Water could not have carried them, because water would have sorted them. Some of them were flattened and scratched. The bed-rock in these regions was smooth and had parallel scratches that ran in a general north-and-south direction. Hard masses of rock that stuck out of the ground were rounded off and scratched. For some time people explained these facts by saying that great floods must have covered the earth and moved these rocks long ago. But scientists began to see a more reasonable explanation.

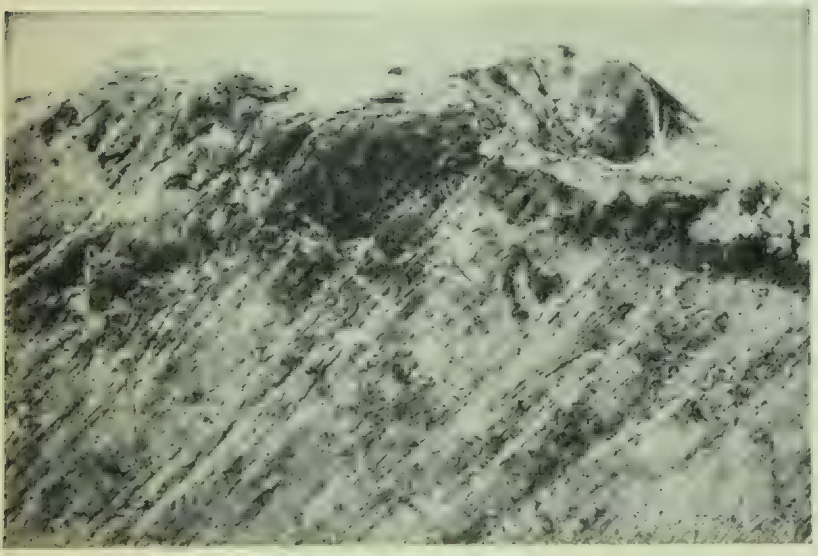

FIG. 321. This mountain side shows the great scratches and grooves that are left in the surfaces of rocks over which glaciers have passed. These scratches are called *striae.*

FIG. 322. The end of Great Glacier, Glacier, British Columbia. Along the edges of the melting ice of the glacier are piles of rock and soil gouged out by the moving ice.

They saw that if a great glacier had come down from the north and covered the territory, the soil and the rocks would be as they are today. We now know that glacial ice has pushed down from the north and melted back again at least four times.

The moving ice of a glacier carries with it all the loose material in its way. Stones held by the ice scrape along the bottom of the valley, smoothing rough places, deepening the valley, and leaving great scratches in the solid rocks. For these reasons a glacial valley is rounded and smooth, not rough and irregular like a valley made by a stream. The scratches on the rock show that a glacier moved over the land and also show the direction in which it moved. You have noticed water streaming from under masses of snow and ice as they melt. A similar thing happens when glaciers melt, except on a much larger scale. Glacial streams may be as big as rivers; therefore, they can wear away the land and carry away much of the material brought down by the glacier.

It is hard to see how a glacier could move out across hundreds or thousands of miles of almost level land and ride over the tops of high hills and low mountains. But scientists have found that Greenland is today almost covered by a glacier that moves in just that way. Near its centre the Greenland ice is a mile and a half thick. The great weight in the centre causes the ice to flow outward toward the edges. The ice that once covered 4,000,000

FIG. 323. These arrows show the directions in which the great North American ice sheet spread. Note that it spread out from three main centres, covering all of Canada, and some of the northern states.

square miles of North America and a large part of Europe probably moved in the same way. The centre of the glacier was far to the north in the cold arctic regions. Glaciers have formed and changed the surface of the earth many times in its history. The last great glacial period ended about twenty-five thousand years ago.

*Self-Testing Exercises.* 1. A mountain valley through which a glacier has passed looks different from a stream-cut valley near by. In what ways are they different and why?

2. List the things that show where a glacier has been at work in the past.

3. Why does the ice in a glacier that is not in a mountain valley move outward from its centre?

*Problems to Solve.* 1. In reference books find out how the ice of glaciers is formed.

2. In reference books read about the glacial periods of the past and also about the places in the world where there are glaciers now. Make a report on your findings. Include such items as size of glaciers, their speed of movement, their thickness, or depth, and how they affect the regions they pass over.

## 2. How are the low parts of the earth built up?

WHERE DOES WATER DEPOSIT THE MATERIAL THAT IT CARRIES? You already know that sediment, such as mud and sand, carried by a stream settles where the water slows down. In young valleys the water runs swiftly along; therefore very little eroded material is dropped. However, in a mature valley the stream runs more slowly. The river forms many curves that gradually widen the floor of the valley. During floods the water spreads over the whole wide valley bottom. Because it runs slowly in the wide space, some of the clay and humus settles on the floor of the valley. This level space that is covered by water when the river overflows its banks is called a *flood plain*.

Usually flood plains are fertile farm land because from time to time they receive new deposits of soil that has been washed off the high ground. The flood plains of such rivers as the Nile in Africa, the Ganges in India, and the Yangtze in China are noted for their rich land. Great centres of civilization have developed on each of these plains because the rich soil made it easy to grow enough food plants to feed large numbers of people.

But most of the mud and sand carried by a stream never gets out on to the flood plain. In old valleys the water is often flowing so slowly that the material is deposited right in the stream bed. This is especially true of the "muddy" Mississippi River. Through much of the river's length the land slopes so gently that the water flows slowly; therefore soil is always settling to the bottom of the river. During floods much of the material is again picked up and carried away.

In places where there are small obstructions in the river, the current is slowed down even more, and more soil settles here. So sand-bars and mud-bars begin to form around these small obstructions. When the river is low, trees and other plants grow upon this soil, and the roots hold the soil in place. During floods more soil is deposited among the plants until large islands are formed. In recent years at Memphis, Tennessee, a huge island, called Mud Island, has formed near the water-front, where Wolf River flows into the Mississippi. At many places in the Mississippi the government spends much money keeping channels open for steam-

FIG. 324. From an aeroplane part of the Mississippi River delta looks like this view. The delta reaches more than 200 miles out into the Gulf of Mexico. The river is continuing to push its delta on outward at the rate of about 340 feet each year.

boats. The government engineers usually apply their knowledge of our second rule of stream erosion. They build *dikes*, or banks, that force the wide river to flow in a narrower channel. Then it must flow faster, and it can pick up and carry material. Thus the river deepens its own channel.

When a river reaches the ocean, the flow of its water is checked by the quiet ocean water. Then its load of sand and mud settles to the bottom. The material that is dropped builds a *delta* out into the ocean. Many famous rivers have built deltas, on which great cities have grown up, surrounded by rich agricultural lands. One of these deltas is at the mouth of the Nile. Here stand the great cities of Cairo and Alexandria. On our own continent a long narrow arm of the Gulf of Mexico once extended all the way to the mouth of the Ohio River. The Mississippi River has filled that whole arm of the Gulf.

But not all the material carried by water is suspended so that it can settle. Dissolved material can be deposited only when the water evaporates or some chemical change occurs. Water that has been seeping through the limestone of cave roofs drips from the roof and runs down the sides. When the water comes out into the air of the cave, some of the dissolved carbon-dioxide gas escapes. Then the water can no longer keep the lime (calcium carbonate) in solution. The lime is deposited in layers on the sides of the cave and in great icicle-like forms that hang down

FIG. 325. For the striking interior decoration of this cave, lime has been deposited both in the form of stalactites and of stalagmites. When a stalactite and stalagmite meet, a *column* is formed.

from the roof. These hanging deposits are called *stalactites*. Where the water drips on the floor of the cave, deposits called *stalagmites* are built up.

However, the greater part of the minerals in solution is carried into streams and finally into the ocean. A smaller part is carried into lakes and seas that have no outlet into the ocean. The water, held in these great basins, is constantly evaporating. The minerals cannot evaporate. As more and more water brings in its load of minerals, the solution becomes stronger and stronger. Through chemical action some of the minerals change to solids and settle to the bottom. Others are used by sea animals to build their skeletons and shells.

Common salt and some other minerals tend to remain in the water; therefore the water is very salty in the ocean and in lakes that have no outlets. If a great body of salt water dries up completely, the salt and any other minerals that are in the water are left on the bottom. Rock salt is believed to have been formed in some such way through the repeated filling and evaporation of a basin of salt water. Rock salt more than 2000 feet thick is found under parts of Louisiana. In Germany there are deposits of salt that are 5000 feet thick.

*Self-Testing Exercises.* 1. Tell how each of the following is formed: flood plain, mud island, delta.

2. What is a stalactite? How is it formed?
3. How does the ocean become salty?
4. How do dikes help keep rivers from getting shallower?

FIG. 326. In Yellowstone Park there are mineral deposits of many shapes and colors around the hot springs and geysers.

FIG. 327. Here is a ridge of glacial drift, material that has been dropped by a glacier. Much of this will be carried away by streams running down the slope as rains fall and snow melts. (Ewing Galloway photo)

*Problems to Solve.* 1. Where have you seen deposits of material left by water? Make as long a list of places as you can.

2. Plan an experiment that you might carry out in a garden to show how water erodes and deposits material.

3. Where would you expect to find the greater number of gravel bars, in the young part of a valley or in the old part of a valley? Why?

4. Read reference books to find out how *natural levees* are formed.

5. How is erosion helpful to farmers who are growing crops on flood plains?

HOW DO GLACIERS BUILD UP THE LAND? In Problem 1 you found that glaciers are powerful agents of erosion. They are able to cut away solid rock, grind much of it into powder, and carry the material which they have eroded far from its original position. All the material transported by the ice is called *glacial drift*. When the ice melts, its load of drift is dropped. Great ridges of it are piled up at the front of the glacier and along its sides. The ridges at the front have been named *terminal moraines*, and those along the sides are called *lateral moraines*. Often the edge of a glacier will remain almost stationary for long periods of time because the glacier moves forward only as fast as it melts at the front. In this way the ice brings down more and more drift and drops it at the same place, piling up a large terminal moraine. Then the glacier will be melted back quite rapidly for a time, only to become stationary again. In this way a series of terminal moraines may be built up by the same glacier. Some-

FIG. 328. These look like ordinary hills to you. They are really moraines that have been built up by glaciers. In most parts of Canada, moraines like these may be found, composed of a mixture of earth, sand, gravel, and small and great boulders.

times masses of glacial clay (powdered rock) and boulders are formed beneath a glacier. These are known as *ground moraines* and may be found in low and otherwise protected places of glaciated regions after the glacier has melted away.

Not all glacial drift stays where it is dropped. The streams formed by the melting of the ice immediately pick up a great deal of the drift and carry it away to form stratified and sorted deposits. These may be found in all possible combinations with the glacial drift. Streams run on top of and underneath the glacier; they pour out into lakes that are formed between the moraines and the edge of the glacier; they cut through the moraines themselves and rush away into larger streams, leaving their deposits of gravel, sand, and clay wherever they go.

From the study of just such deposits as you have been reading about, we know of the great ice sheet that once covered much of our country. From the Atlantic coast to the mountains of the West and as far south as the Ohio and Missouri rivers is a great layer of drift, hundreds of feet thick in some places, which could only have been brought there by a glacier or a series of glaciers. Scattered through this drift are boulders of granite, although underneath the *drift sheet* in most places lie only other kinds of rock, such as sandstone and limestone. In the Canadian Shield region are the main bodies of granite of the same type as the boulders, and from which the boulders must have come. Buried

FIG. 329. Many of the pebbles and boulders in glaciated regions are granite. Bed-rock of granite is found in the Canadian Shield and in the mountains of the West. This great boulder, therefore, must have been broken off and carried hundreds of miles by the glacier.

beneath the mass of glacial drift are the valleys of streams that existed before the glacier came.

Upon the surface of the glacial drift are the sand and mud deposits and the old beach lines of a number of large lakes formed while the ice closed the outlets of rivers flowing northward. Here and there over the region are ranges of low hills that are the moraines piled up by the glacier. Hollows left among the moraines when the ice withdrew are still filled with innumerable lakes and swamps. If it had not been for the work of this great glacier in tearing down the high places, filling up the low places, and digging out huge basins, the largest of which are occupied now by the Great Lakes, the appearance and history of Canada would have been quite different.

*Self-Testing Exercises.* 1. What is glacial drift? How is it different from materials deposited by water?

2. What are moraines? How are they formed?

3. Make a list of points that you could call, "Scientific evidence that glaciers once covered part of our country."

*Problems to Solve.* 1. Has your locality been covered by glacial ice? Ask questions, read, and study the map on page 464 to answer this problem. If your region has been covered by a glacier, what evidence can you find in your locality? List the evidence.

2. How is transportation of materials by ice like transportation by water? How is it different?

How does wind build up the land? Wind, being an eroding and transporting agent, is also a builder. Its work is most noticeable along lake and ocean shores and in desert regions, for, as you have already seen, wind is only able to pick up material where the soil is dry and barren. Along a beach the sand washed up by the waves soon dries. This dry sand is blown along until some obstruction, such as a stone or a plant, interferes with the moving air. Then it is dropped behind the obstruction and forms a little mound which is itself an obstruction. The sand continues to be blown up the face of the mound and dropped at the back until a large *sand dune* is formed. In Prince Edward County in Ontario, a line of dunes several miles in length has been moved inland by constant winds, in some places a distance of three miles. Unless held by plants, the dunes are slowly moved forward by the wind. Large ones sometimes travel as much as fifty feet a year, and they bury forests, streams, and houses. The sites of ancient cities in northern Africa and southwestern Asia have been hidden for hundreds of years by wind-blown sand that has piled up over them to make quite high hills.

In many places in the world geologists find deposits of fine material hundreds and even thousands of feet in depth which they believe have been at least partly formed from wind-blown dust. *Volcanic ash* is also blown away from its source by the wind, to fall over large areas, and even in distant places, in depths varying from a thin covering to many feet. The eruption of an Icelandic volcano in 1783 threw out dust which destroyed the crops in Scotland 700 miles away.

From what has been said you can see that the soil which covers the surface of a large part of the world is *transported soil*. It has been brought to its present location by the action of moving water, ice, or air. However, not all of the material that has been moved into the low parts of the earth's surface by these agents now exists as soil. A very large part of the transported materials has been changed into rock, as you will soon learn.

*Self-Testing Exercises.* 1. From what kind of land surface can wind most easily move soil?

2. Explain what this statement means: Most of the surface soil of the earth is transported soil.

Fig. 330. Here are strata of two kinds of sedimentary rocks—limestone and shale. The light-colored layers are limestone.

*Problems to Solve.* 1. Tell the story of how dune sand may be changed into fertile soil.

2. How do waves help make sand dunes along an ocean or lake?

How are rocks formed from eroded material? You have often heard of limestone and sandstone. But did you ever hear of *shale* and *conglomerate?* These four different kinds of rock—limestone, sandstone, shale, and conglomerate—are formed from materials that have been eroded and transported by water, wind, and ice. Because they are found in layers, or *strata*, they are sometimes called *stratified rocks*. And because they are formed in part from sediment in the water, they are sometimes called *sedimentary rocks*.

*Experiment* 77. WHAT ARE THE CHARACTERISTICS OF THE COMMON SEDIMENTARY ROCKS? For this study you will need samples of shale, limestone, and sandstone. These are the more common sedimentary rocks. Each piece of rock is called a *specimen*.

*a*) Study the general appearance of each kind of rock. Do glass-like crystals show in any of the specimens? If so, in which ones? Which has the finest grains in it? Can you see shells of animals in any of the specimens? Use a magnifier in your study if you have one.

*b*) Scratch each specimen with the point of a knife to test its hardness. Also try to scratch each specimen with a piece of glass.

*c*) Wet each specimen and smell it carefully.

*d*) Put a drop of hydrochloric acid on each kind of rock. Which one "boils" up most vigorously? (Calcium carbonate will give off carbon-dioxide gas when it is touched with an acid. You can use this test if you do not recognize limestone easily. However, marble, a kind of changed limestone, acts the same way.)

Limestone is usually light gray in color. It is formed at the bottoms of bodies of water, mainly from the shells and skeletons of animals. The sea animals (and sometimes plants) take dissolved calcium compounds from the water and build them into their own bodies. When the animals die, their bodies fall to the bottom of the water. The soft parts decay, but the skeletons and shells gradually build up the bottom. More and more material of the same kind settles on top, the pressure becomes greater and greater, and the whole mass of shells and skeletons is finally changed into a layer of rock.

The other three kinds of sedimentary rocks are made from the various sizes of material deposited by water or wind. Sinking of the land, about which you will learn in Problem 3, allows these deposits to be covered with water and with more material washed down by the water. Water then soaks through the materials, carrying minerals, while the material on top presses the lower layer closely together. Crystals of the dissolved minerals and the great pressure gradually fasten the pieces of gravel together to make conglomerate. The sand becomes sandstone, and the mud becomes soft shale.

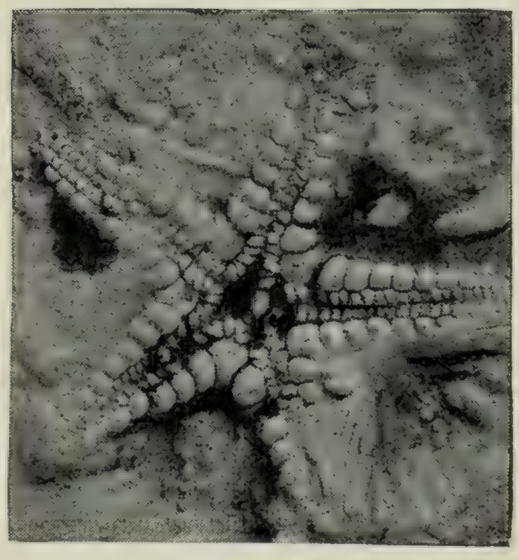

FIG. 331. A fossil starfish found in rock far from any bodies of salt water (Walker Museum, University of Chicago)

The remains of plants and animals, called *fossils*, are often found in sedimentary rocks. It is easy to see how they got into these rocks. The bodies of animals that died settled to the bottom of the sea, where the limestone was forming. Or they were buried in mud or sand that later became shale or sandstone. The soft parts decayed, but the hard parts remained or were changed to stone. There we find them in the rocks today. Even the tracks of prehistoric reptiles are found preserved in the rocks.

Under great heat and pressure far down in the earth sedimentary rocks are sometimes changed into harder kinds of rocks.

Among these kinds of "changed" rocks are *marble* and *slate*. Marble is formed from limestone and sometimes shows the fossil shells from which it was made. Slate is formed from shale, which, as you know, is formed from mud.

*Self-Testing Exercises.* 1. Name three kinds of sedimentary rocks and tell briefly how each kind is formed.

2. What kind of rock may be changed into marble? What kind of rock may be changed into slate?

*Problem to Solve.* What kinds of rock are found in your locality? Gather specimens of the solid rock that underlies the soil. You can often find the rock exposed in beds of streams, along hillsides, or in quarries. Study the specimens and decide which kind or kinds of sedimentary rock you have found. Have your opinion checked by a teacher or by some other person who knows rocks.

## ¶ 3. How are the highlands renewed?

YOU HAVE BEEN LEARNING how the surface of the earth is being constantly eroded. Can you tell what will happen to a great body of land that is continually eroded by water, wind, and ice? Rivers and waves tear down the high places and leave the material at lower levels. For the most part ice does the same thing. Only wind is able to raise material to higher levels. But it cannot raise soil to a very high place. Dunes built by the wind are never more than a few hundred feet high. You can see, then, that a great continent with its plateaus and mountains is gradually worn down by erosion, and its materials are carried away to the oceans. Unless other changes occur, this wearing-down process continues through millions of years until the streams flow too slowly to carry any eroded material. But other changes do occur—changes that lift up the surface of the earth. In this problem you will learn how the land is raised to higher levels.

HOW DO VOLCANOES BUILD UP THE EARTH'S SURFACE? For centuries people cultivated vineyards and led their cattle to pasture on the sides of a great mountain called Vesuvius, in Italy. Two ancient towns, Herculaneum and Pompeii, lay at the foot of the mountain. In 79 A.D. earthquakes occurred, the top of the mountain burst open, and a shower of stones and ashes from the mountain buried Pompeii and Herculaneum so deep that

they were completely lost for most than 1500 years. For some years Vesuvius was quiet; then again it poured out gases, ashes, and melted rock, or *lava*. By the year 1150 there had been eight great eruptions since the eruption of the year 79 A.D. Other terrible eruptions took place in 1872 and 1906.

Such is the story of one great volcano. What causes these destructive explosions and outpourings of melted rock from down in the earth? Do all volcanoes erupt as Vesuvius has done? Why do some volcanoes seem to have ceased erupting? Geologists have studied these and other problems about volcanoes for a long time. They have learned a great deal, but they have not yet learned the real causes of volcanic activity. You would probably like to know what causes the great heat that melts rocks and sends out steam and poisonous gases. However, that is one of the things that geologists have not found out. Some geologists have thought that the heat is caused by the great pressure of the earth's outer layers on the layers below. Or it may be heat that is left from the time when the earth was formed. In the last fifty years scientists have learned about radium and similar elements that give out heat energy all the time as they change into other substances. Thus it may be that the heat inside the earth is caused by these *radioactive* elements.

FIG. 332. When a volcano erupts many times, it slowly builds up a mountain that may be thousands of feet high.

Even though we do not know the cause, we do know that the earth gets hotter and hotter the farther down we dig into it. In deep mines and wells the temperature rises on the average one degree Fahrenheit for each fifty feet. At this rate the temperature forty miles down would be more than 4000° F. That is much hotter than is necessary to melt the rocks. However, the pressure of the rocks above keeps most substances from melting at their

usual melting temperatures. Scientists have other reasons for believing that most of the rock deep in the earth is not melted. They think that the rock may be *plastic,* or putty-like, so that it yields slowly to pressure, but the rock is probably not liquid.

In some way masses of rock do melt deep in the earth. Perhaps they do so because some change in the earth's crust releases the pressure on them. When they have melted, the liquid rock begins to work its way toward the surface. Sometimes it never reaches the surface. Instead, it pushes its way in between layers of solid rock and begins to cool and harden. As it cools, crystals of several kinds of minerals may form. The more slowly they cool, the larger the crystals grow. Here is an experiment that will show you how crystals grow. But instead of melting a substance to get crystals, you will dissolve the substance and then get the crystals by cooling.

*Experiment 78.* HOW ARE CRYSTALS FORMED? (*a*) Stir some copper sulphate or some powdered alum into a small vessel of hot water until no more will dissolve. Then heat the solution to the boiling point again and keep adding alum as long as it will dissolve. Remove the vessel from the fire and use a string to hang a small nail in the centre of the vessel. Set the vessel in cold water to cool quickly.

*b*) Repeat part *a*, but wrap the second vessel with many thicknesses of cloth or cotton and cover it so that it will cool slowly.

After several hours study the results. Did crystals form in both vessels? In which are they larger?

In many places on the earth erosion has uncovered masses of rock that are made of crystals. The sedimentary rocks next to these masses show the effects of great heat. For these reasons geologists are quite sure that the crystallized rocks were melted and then hardened. Because they were formed by heat, they are called *igneous rocks*, which means "fire-formed" rocks. Granite is one of the most common igneous rocks. You can usually see three different minerals in the form of crystals in granite. One kind, called *mica*, is clear and glistens. It is soft and flaky when scratched with the point of a knife. Another is quartz that looks like dull glass and is too hard to scratch with a knife. (See page 453.) The third, called *feldspar*, is duller and less transparent than quartz or mica.

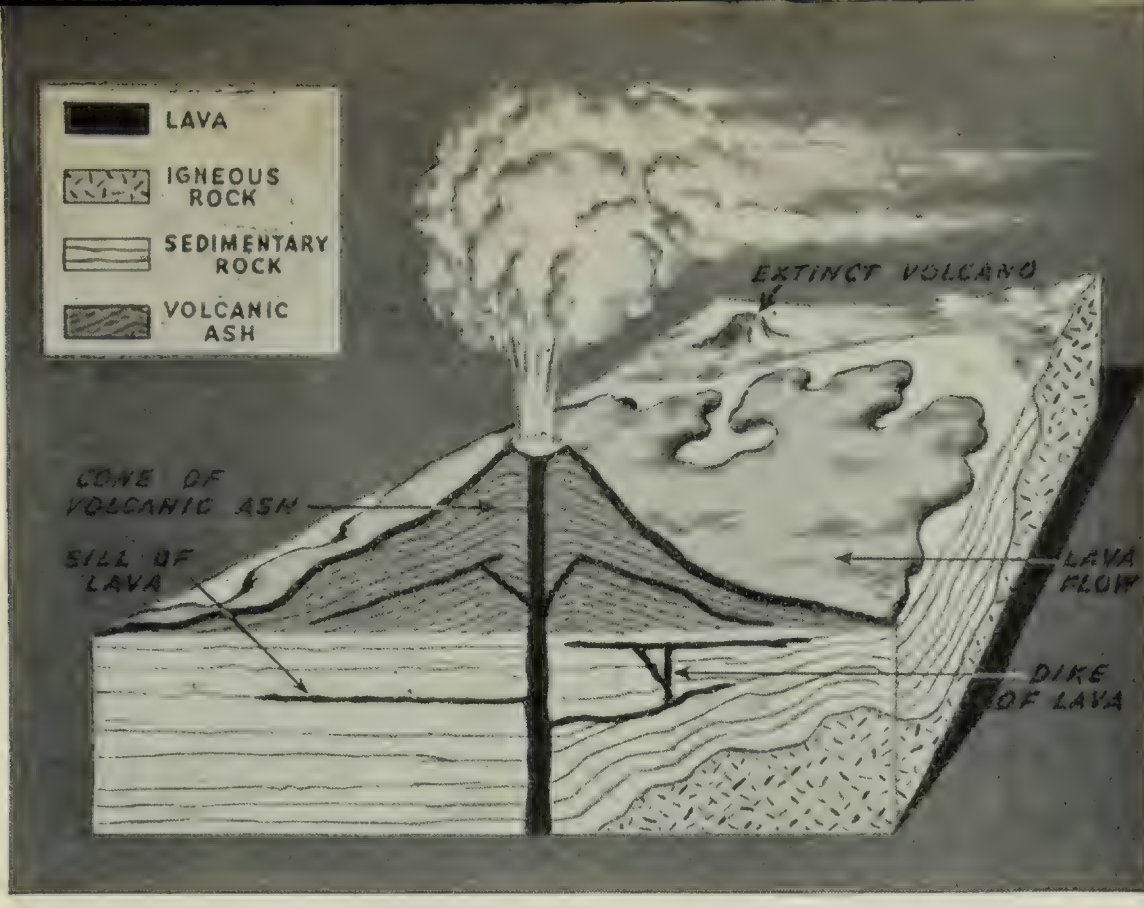


FIG. 333. This block represents a section of the earth cut through a volcano to show its structure. At the upper left you will find a key to help you locate the lava and different kinds of rocks in the drawing. A *sill* is lava that pushes in between layers of sedimentary rock and hardens. A *dike* is formed when lava pushes up, fills a crack in rock layers, and hardens.

When the melted rock works its way close to the top of the ground, volcanoes are formed. Often the melted rocks contain gases under great pressure. The pressure is released when the rocks above give way. The sudden expansion of the gases then causes explosions. Explosions may also be caused by steam from the water in the earth. These explosions blow the melted rock into pieces of different sizes and shoot it high into the air. Here it is cooled and hardened into volcanic ash and "cinders" that fall about the crater. The melted rock may continue to rise and pour out on top of the ground as lava. Cinders, ash, and lava build up the mountains we call volcanoes.

Some volcanoes remain active and erupt at intervals as Vesuvius has done. Others are closed by the cooling of the lava inside them and never again have an eruption. They are then said to be *extinct*. Many volcanoes have never been active since man has known them. Canada has no active volcanoes, yet volcanic soil is found scattered through Quebec and Ontario, in New Brunswick, and in the south-west of the Canadian prairies.

You must not think that all lava comes from volcanoes. In several parts of the world in prehistoric times great cracks opened through the rocks, and lava poured out over wide areas. One such

FIG. 334. This is the way the dark lava that has flowed around Kilauea, a great volcano of Hawaii, looks. Many islands, including the Hawaiian Islands, have been built up by the eruption of volcanoes that lie under the surface of the ocean.

lava flow originated the Selkirk and Coast mountain ranges in British Columbia. Many thousands of years ago a series of volcanoes affected the west of the continent, from the foothills across the Rockies to Vancouver Island and the Queen Charlotte Islands. Erosion, in the ice age, stripped the mountains, and volcanic deposits were carried to the nearby plains. By erosion and by weathering lava is changed into soil. Weathered lava makes rich soil. Much of the fertile wheat land of Alberta and southern Saskatchewan has been formed from weathered lava.

*Self-Testing Exercises.* 1. Tell briefly the story of Vesuvius.

2. (*a*) How do we know that the inside of the earth is very hot? Give at least two reasons. (*b*) Give three ways in which the inside of the earth may have got its heat.

3. Explain briefly how masses of igneous rock are believed to be formed in the earth.

4. How can scientists tell whether a specimen of igneous rock cooled slowly or rapidly?

5. How are volcanic ash and cinders formed?

6. Do all lava flows come from volcanoes? Explain.

*Problems to Solve.* 1. Explain why igneous rocks do not usually show layers like those found in sedimentary rocks.

2. Why are fossils never found in igneous rocks?

3. Find some specimens of granite in your locality. Examine pebbles and boulders from the soil, paving blocks, and large buildings. If you think you have found some granite, have your opinion checked by someone who knows. Probably a shop that cuts and sells gravestones will give you chips of granite.

4. What are some famous volcanoes besides Vesuvius? Read in reference books about Mt. Etna, Krakatoa, Mauna Loa, Pelée, Shasta, and Stromboli.

HOW ARE MOUNTAINS AND PLATEAUS FORMED? Mountains present many puzzling facts to those who think. How were they made? Have they existed ever since the earth was formed, or has some change in the earth pushed them up miles above sea-level? Some mountains are rough and jagged; others are round and smooth. Why? High on the sides of Mount Everest, and on other mountains in different parts of the world, are sedimentary rocks containing fossils. These rocks must have been made in the bottom of a sea! How did they get up so high? Why are the layers of rock tilted up on edge in some mountains and bent into great folds in others? Why are some mountains made of igneous rocks instead of sedimentary rocks? Geologists try to find the answers to these and other questions as they study the earth's crust.

Scientists have discovered many facts to prove that the earth's land surface does not remain at the same level above the sea. The northern part of the Atlantic coast has been sinking (or the sea has been rising) during recent geological ages, that is, within the last 100,000 years. We know this because the valley of the St. Lawrence River and the valley of the Hudson River extend out into the ocean beneath the water for hundreds of miles. Great gorges are found in the rock of the ocean floor. Through these gorges the rivers once ran. But these rivers could not possibly have dug valleys beneath the ocean. Instead, the rivers would tend to fill up the ocean near their mouths, as you learned in Problem 2. Therefore these undersea valleys must have been at one time above the level of the ocean. Then, either the land sank or the ocean water rose.

Scientists have reasons for believing that the land sank. In the neighborhood of Lake Champlain, in New York, there is a beach

now 500 feet above the lake. It is not a lake beach, either, for the shells in the sand are those of ocean animals, and the skeleton of a whale was once dug up in an inlet along the old shore-line. These facts show that much of New York was once lower than it is now, and that the ocean water once flowed over it. Sedimentary rocks also tell us that great areas of land were once under water, because practically all sedimentary rocks were formed beneath bodies of water. Thus you can tell, whenever you see limestone, sandstone, or shale, that the places where you see them were once on the bottom of a sea.

The rising and falling of the earth's surface and other changes in the positions of rocks have been given a big name by geologists. These changes are called *diastrophism*. Scientists do not know the exact causes of diastrophism, but they are learning more and more about it. Many facts make them believe that there is a balance between the different parts of the earth's surface. They have found that the rocks of continents are lighter than the rocks in the deepest parts of the ocean. The continents, they believe, were raised up by the sinking of the heavy rock around them. This heavier rock sank deeper toward the centre of the earth and pushed the lighter rock up to higher places. Thus, the heavier parts of the earth are balanced by higher masses of lighter rock in other parts of the earth.

The great unknown forces that cause diastrophism seem to act in several ways. Sometimes they raise or lower the rocks in the earth's crust. At other times they stretch the layers of rock. And more often the layers are pressed in from the sides, as shown in Figure 335. If you make a pile of long sheets of paper or strips of paper and push against the ends, what will happen? The layers of paper will bend upward in some places and downward in others. They will bend and fold over farther and farther until some of the layers are in the shape of an "S." Rocks seem to behave in much the same way.

As the rocks are bent and folded, great breaks may occur so that one part of a rock slides past another. Sometimes one side is pushed over the other for miles. A break in the rocks where one side moves past the other is called a *fault*. But the rocks are not always pushed over one another at a fault. Sometimes the rock

Fig. 335. Geologists find almost every possible kind of bending and folding of the layers of sedimentary rock. Notice how these layers are bent upward into an arch.

on one side moves up, and the rock on the other side moves down. Or a block between two faults may be pushed up higher than the rocks on either side. These faults may be hundreds of miles long. Not a year passes without several violent earthquakes being reported in the newspapers. Some of the quakes are caused by volcanic activity. Others are caused by diastrophism. When a fault is made, the rocks do not seem to move slowly past each other. Instead they "stick" until the force becomes very great. Then there is a sudden jerk as the rocks slip past each other. This jerk starts the earthquake. One of the most disastrous earthquakes in North America destroyed a large part of San Francisco in 1906. A crack in the earth 300 miles long showed where the rocks had slipped.

Now you can understand some of the changes that make mountains and mountain ranges. When a thick layer of the rock is bent upward, a range of *folded mountains* is formed. Or a fault may form, and the rocks on one side of the fault will be lifted up into a great sloping ridge. At other times the land between two faults is raised and tilted to form mountains called *block mountains*. When such changes lift a large area above its surroundings, the area is known as a *plateau*.

Mountains, as we see them today, are not formed by movements of the earth's surface alone. As soon as a part of the land begins to be lifted, erosion begins to tear it down and change its

shape. Through the millions of years that the mountains are slowly rising, erosion is gnawing away at their tops and sides. The rocks that are easily destroyed are carried away. Layers and ridges of hard rock are left. Some mountains are only the hard parts of old plateaus or the ridges that have been left as streams carved out their valleys. The mountains of the West are rough and rugged because they are comparatively young. The rocks in the mountains of Quebec show all the folding and wrinkling of rugged mountains, but these mountains are much older than those of the West. Therefore they have been worn down until they are rounded and low.

FIG. 336. Read again the description of the different kinds of faults and tell what probably happened when this fault occurred. Do you think it occurred very recently?

*Self-Testing Exercises.* 1. Give some reasons for believing that land rises and sinks with respect to the level of the ocean.

2. Name at least four effects of diastrophism.

3. By a diagram or with modelling clay show what a fault is.

4. Draw a diagram to show how mountains may be produced by folding and erosion of thick layers of rock.

5. Name two causes of earthquakes.

*Problems to Solve.* 1. How can you tell an ordinary mountain peak from a volcano?

2. Tell the story of a block of limestone that is now perched high on one of our western mountains.

3. Use clay, paper, or cloth to show how rocks are folded, as described on page 480.

4. Draw a diagram to show how the heavy rocks beneath the ocean would cause light rocks to stand high in the continents.

5. Find out some of the ways in which diastrophism has changed the earth in the locality where you live.

## Looking Back at Unit 14

1. Turn to the Table of Contents and find the list of problems for Unit 14. With this list before you, write a short composition in which you answer the question, "How Does the Earth's Surface Change?" Be sure that your answer includes the answers to all four problems of the unit.

2. Make a list of the things you have learned in this unit that you think are most interesting and valuable to you.

3. Show that you know the meaning of the following words:

| | | | |
|---|---|---|---|
| *block mountain* | *plateau* | *strata* | *stalagmite* |
| *flood plain* | *moraine* | *quartz* | *diastrophism* |
| *conglomerate* | *erosion* | *delta* | *weathering* |
| *igneous rock* | *fault* | *humus* | *sediment* |

## Additional Exercises

1. Make a list of all the different ways in which rock is used in your locality.

2. How are icebergs formed from glacier ice?

3. How does erosion produce waterfalls? (Geology and physical-geography books will help you answer this.)

4. What are ox-bow lakes, and how are they formed?

5. In some regions when a farmer digs up a rock that is rounded and rather soft on the outside, he says that the rock is growing. Do you think that his opinion is correct? Why?

6. How much salt is there in a gallon of ocean water?

7. Does salt in water make mud settle more quickly? Plan an experiment that will answer this question.

8. The bottoms of some of the Great Lakes are below the level of the ocean. How could they have been eroded so deeply?

9. Learn to read *contour maps*. This kind of map is used a great deal by geologists. You can find some contour maps in geology books and physical-geography books, together with explanations of their meaning. Also, write to the Surveyor General, Department of the Interior, Ottawa, to find if a topographical map of your locality has been made. If so, obtain one and see what you can learn from it.

10. Do you think that rocks are being formed today? Where?

11. Write to the Bureau of Geology and Topography in Ottawa for information about the geology of the place where you live. If possible, take a trip to see some of the main geological formations.

12. Collect articles from newspapers and news magazines about such happenings as earthquakes, floods, and volcanic eruptions. Make them into a carefully organized clipping book. Include maps on which you mark the place where each happening occurred.

13. Prepare a "Book of Scenic Wonders" in which you collect information about such places as Grand Canyon, Roche Percée, and Banff National Park and their geological history.

14. Find out about petrified forests and how they were formed.

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WHEN OUR COUNTRY WAS FIRST SETTLED, almost all work had to be done with the energy of muscles—the muscles of men and of animals. Today, in the home, on the farm, and in the factory we use kinds of energy about which the early settlers knew nothing. Even fifty years ago men did not know about the energy that makes this tractor run so that it can furnish power to thresh wheat, blow the straw on to the stack, pull plows, and in other ways make things move. But just knowing about different kinds of energy could not help men do work. They had to find ways of harnessing the energy just as it is necessary to harness a horse to use its energy for pulling a wagon or a plow. In this unit you will learn some of the important things that man had to discover about energy and the ways of harnessing it. (International Harvester Company photo)

# UNIT 15

# How Do We Harness the Energy of Nature to Do Our Work?

## Looking Ahead to Unit 15

YOU HAVE ALREADY LEARNED what we mean in science when we talk about doing work. Work is overcoming some resistance, moving something that resists being moved. In this world there is a great deal of work to be done. Materials of various kinds have to be lifted, sawed, cut, ground, and mixed. Soil has to be cultivated. Tunnels, ditches, and canals have to be dug. Water must be pumped, and fibers spun into thread, woven into cloth, and sewn into clothing. Men and goods must be carried about over the earth. Books, magazines, and newspapers must be printed. Radios, telephones, and telegraphs must be operated. As you know, energy is needed whenever any of these kinds of work is to be done.

Before you study the different ways that we use to harness energy, think about some of the things that you already know about energy (pages 103-105). You remember that energy can do things. It can make things move, and it can cause changes to take place in matter. Foods, gunpowder, fuels, and storage batteries, for example, possess energy, as you know, for they can produce motion when they go through chemical changes. An object, such as a rock, a pile-driver, a clock weight, or a human being, when in a certain position, can fall or move toward the earth. In so doing it can exert a force through a distance, moving other objects as it goes. A coiled clock spring, a bent bow, a bent springboard, or a stretched rubber band can move objects; therefore they possess energy. In all of the cases mentioned in this paragraph, the materials possess energy because of their chemical composition, their position, or their condition. This kind of energy is called *potential* energy, or stored energy.

FIG. 337. These men stored energy in their bows when they bent them. When they release the bows, the energy will be given out again and used to speed the arrow toward the target. (American Forestry Association and Henry Clepper photo)

Another kind of energy is known as *kinetic energy*. Any material or object in motion, such as a meteor, a baseball bat, an automobile, a train, a cannon ball, molecules of steam, molecules of gas in a gas engine, aeroplanes, a falling body, falling or running water, air as wind, or a current of electricity, can cause another material to move. This kinetic energy, or energy of motion, is sometimes known as *active energy*. Other terms used to describe energy are chemical energy, heat energy, electrical energy, light energy, mechanical energy, and muscular energy.

The water-wheel, the steam engine, and the gasoline engine, which you will study in this unit, are devices that man has invented to harness energy. You have already seen that one kind of energy can be changed into another kind. In Unit 5 you learned that the energy of sunlight is changed into chemical energy in the green plant. The scientist calls this change a *transformation of energy*. In each of the machines that you will study in this unit one kind of energy is changed into another kind of energy to do work for us.

How are these power machines important to you? What difference do they make in your life? The answers to these questions depend on who you are and where you live. On the average, machines are doing as much work for each person in our country as ten people could do working constantly. This means that, on

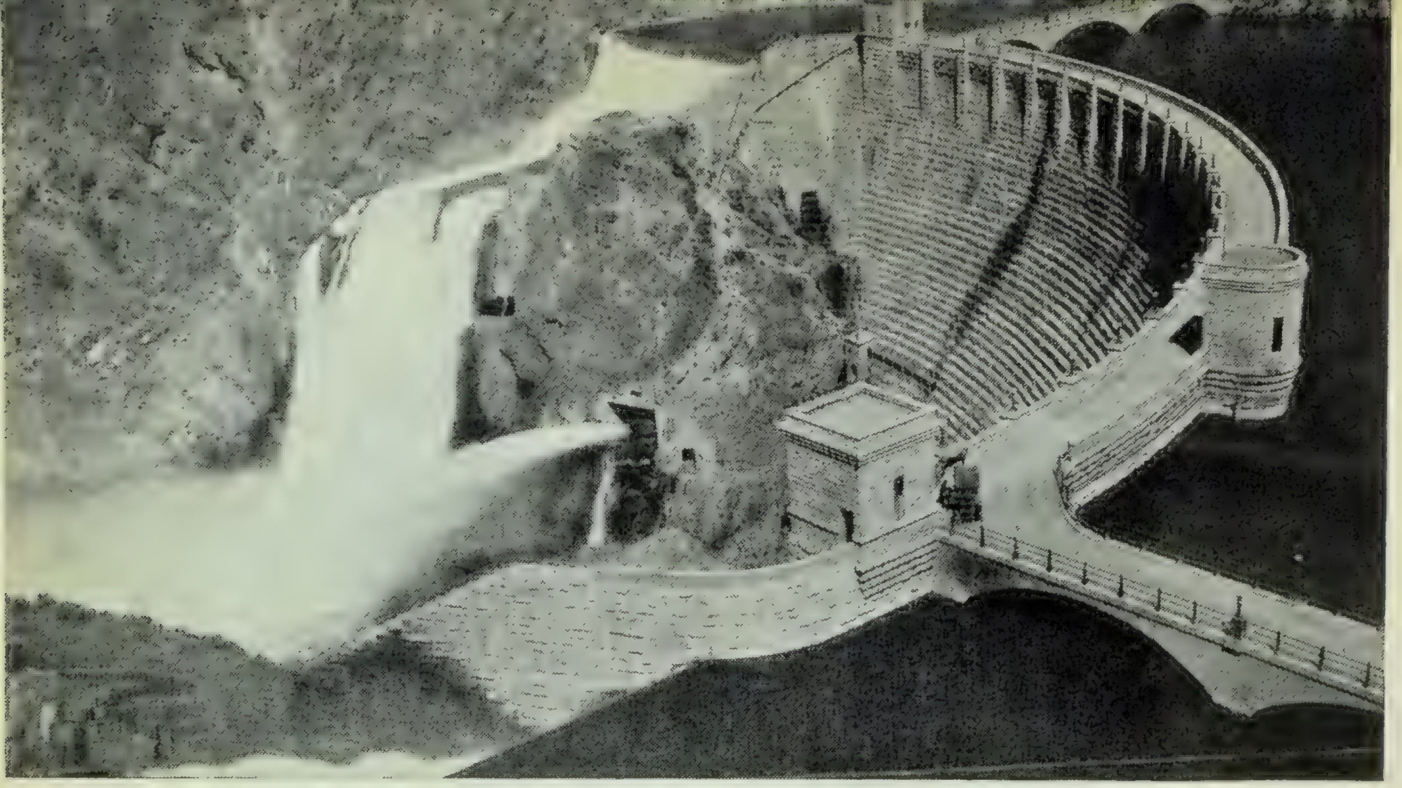


FIG. 338. The water at the top of the dam has stored-up, or potential, energy. As it falls, this energy changes to moving, or kinetic, energy, which can do work.

the average, each of us can have better food brought greater distances, more and better clothing, better homes, more music, books, education, and leisure and can travel farther and more easily than our great-grandfathers could.

From these facts you can see that the machines which harness the energy of nature are very important to you and to your country. You will want to know many things about them. How can water power-plants make electrical current? How do steam engines work? What is a steam turbine? How does gasoline make an automobile go? How are Diesel engines different from other engines? What is a horse-power? Where does all energy come from? What will happen when all our coal and oil are gone? In this unit you will find the answers to most of these questions.

## ¶ 1. How is the energy of wind and water put to work?

YOU HAVE OFTEN SEEN THE WIND doing work. The slightest breeze rustles the leaves of trees and moves their branches back and forth. A strong wind pushes you as you walk along, and sends hats whirling. Tornadoes tear houses apart and lift the pieces and carry them far away. Moving water does work, too. You have read in Unit 14 how it carves great river valleys out of solid rock. Water can exert a greater force than wind and can

move heavier objects because it is much denser than air. Let us see how machines are made to harness the energy of wind.

How is wind harnessed? The first harness made for the wind was probably on some small prehistoric boat. It was, in some ways, much like the harness made for a horse. Men in the boat fastened a small sail to sticks of wood and held it up for the wind to push against, just as a horse pushes against the collar of its harness. But today, sails are seldom used except for pleasure boats and the boats of savages who have not learned to use steam or gasoline engines. However, many windmills are still in use for doing work. The energy of wind is already kinetic energy, because wind is air that is moving. All that we need to do to harness wind to a machine is to get the moving air to make something go round and round or back and forth.

Fig. 339. A wind-operated generator

In the last few years many windmills like the one in Figure 339 have been put on the tops of farm buildings. These new windmills generate electricity for many purposes. They change the energy of moving air into electric energy. The windmills attached to electric generators work just like a little "pin-wheel" that spins when you hold it in the wind. The wind strikes the upper blade at an angle. Since the blade cannot move in the same direction as the wind, it moves to the right. The lower blade slopes the opposite way. Thus it moves to the left as the wind goes past it. With one blade pushing to the right and the other to the left, the shaft of the windmill turns and drives an electric generator. In this way the constant forward motion of the wind is changed into the rotary, or turning, motion needed for the generator. Small windmills of this type have been made so efficient that one foot of wind pushes the tip of a propeller through a distance of thirteen feet.

In the windmills that operate pumps the *rotary motion* must be changed into *reciprocating (back-and-forth) motion.* Two small gears on the shaft of the propeller turn two large gears (Figure 340). A few inches from the centre of each large gear wheel is a short pin extending out something like the handle of a crank. This is called an *eccentric* (meaning "off centre"). Attached to the two eccentrics are two arms with a crosspiece at the top. As the eccentrics rotate, the crosspiece moves up and down. Thus the rotary motion of the propeller is changed to the reciprocating motion of the pump rod. Each propeller is fastened to a pivot and provided with a "tail," or fan, so that the propeller always faces the wind when it is running. The propeller can be turned parallel to the tail. Then it no longer faces the wind and will not rotate.

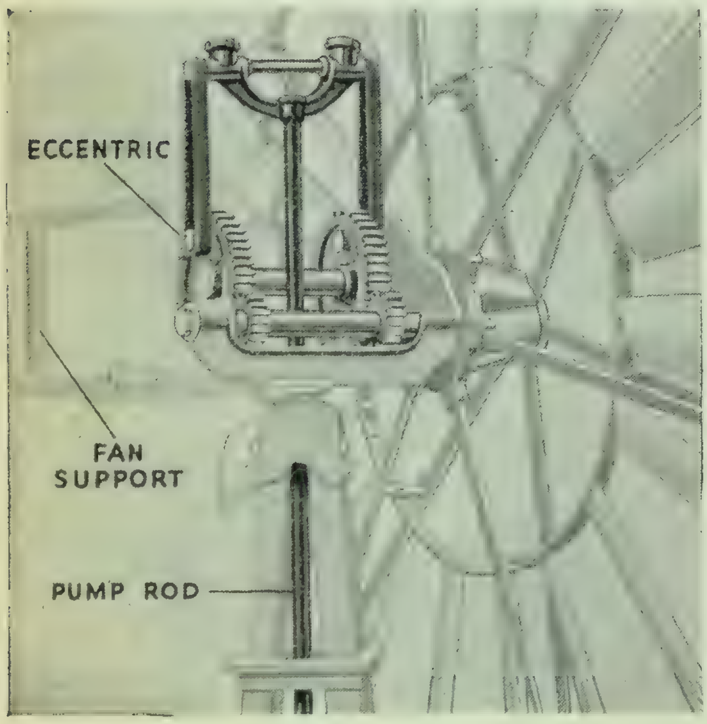



FIG. 340. A windmill eccentric

*Self-Testing Exercises.* 1. Name three kinds of work done with the energy of wind.

2. What is rotary motion? Reciprocating motion?

3. Tell how a simple windmill changes the motion of the wind into rotary motion.

*Problems to Solve.* 1. Give one reason why we do not use the wind to do much of our work.

2. What is one advantage of using wind as power?

HOW DO MODERN WATER POWER-PLANTS WORK? Only a few of the water-wheels of colonial days in our country are still in use. Many that are still running are of value chiefly as antiques. These wheels were of two main types, the *undershot wheel*, in which running water struck the blades at the bottom of the wheel, and the *overshot wheel*, in which the water poured into buckets at the top of the wheel. The undershot wheel was used where there was a great amount of water from a low dam. The overshot wheel (Figure 342) worked best where a higher source

FIG. 341. Undershot water-wheel

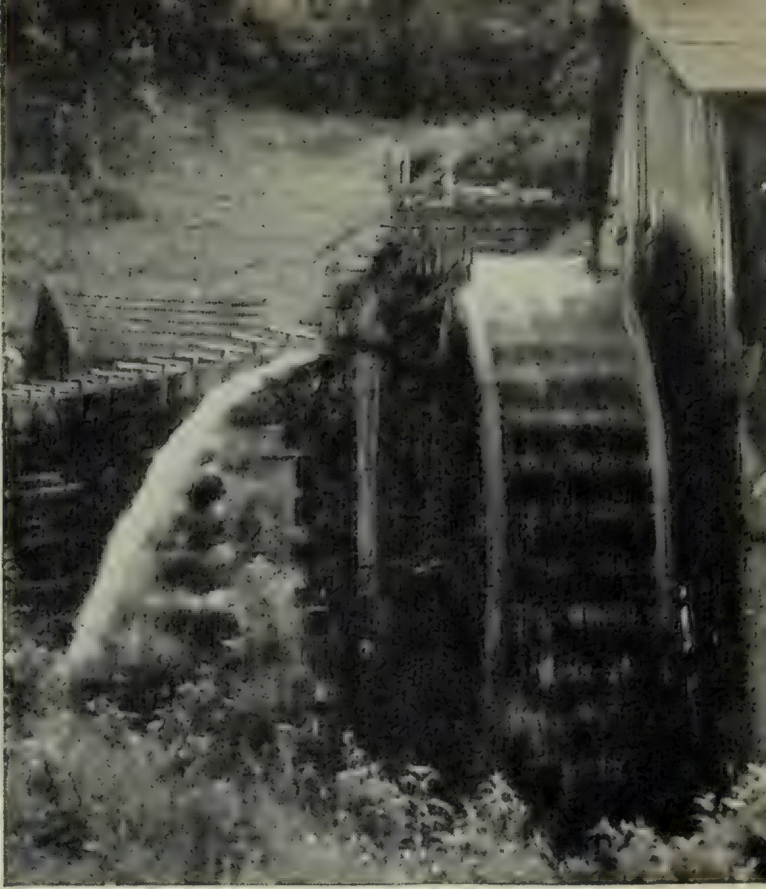
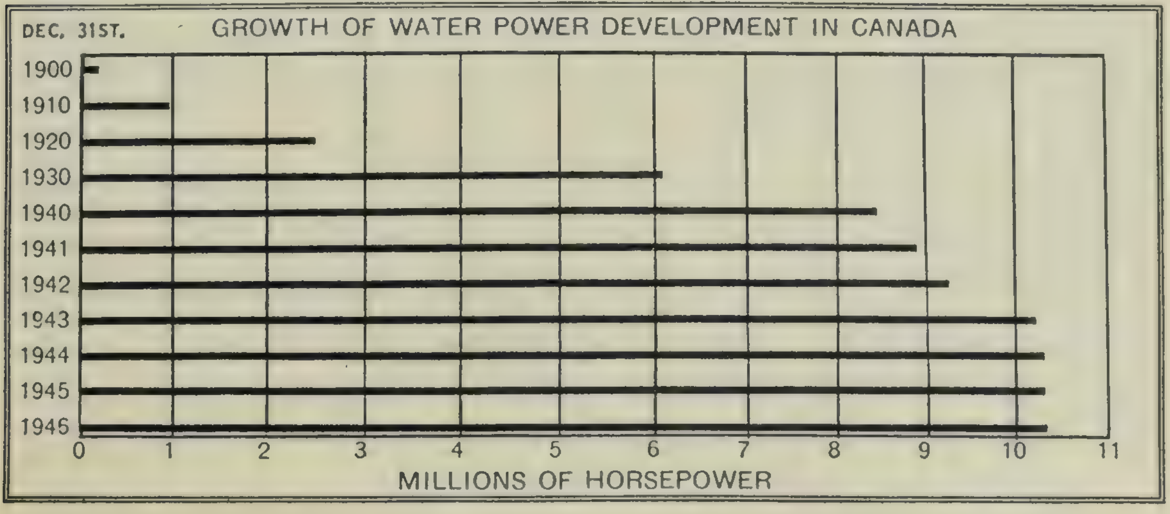


FIG. 342. Overshot water-wheel

of water was available. The water at the top of this wheel possessed potential energy. As gravity pulled it downward, the potential energy of the water changed into kinetic energy and made the wheel rotate. You can see that both these kinds of water-wheels are simple wheel-and-axle machines.

Scattered here and there along the streams of our country are many small water power-plants used for small mills and small electric generators. However, the most important plants, which supply power for large-scale domestic and industrial use, are those at great dams or falls where large amounts of water are available. Though the industrial districts of Canada are poor in coal, they are rich in rivers and waterfalls.



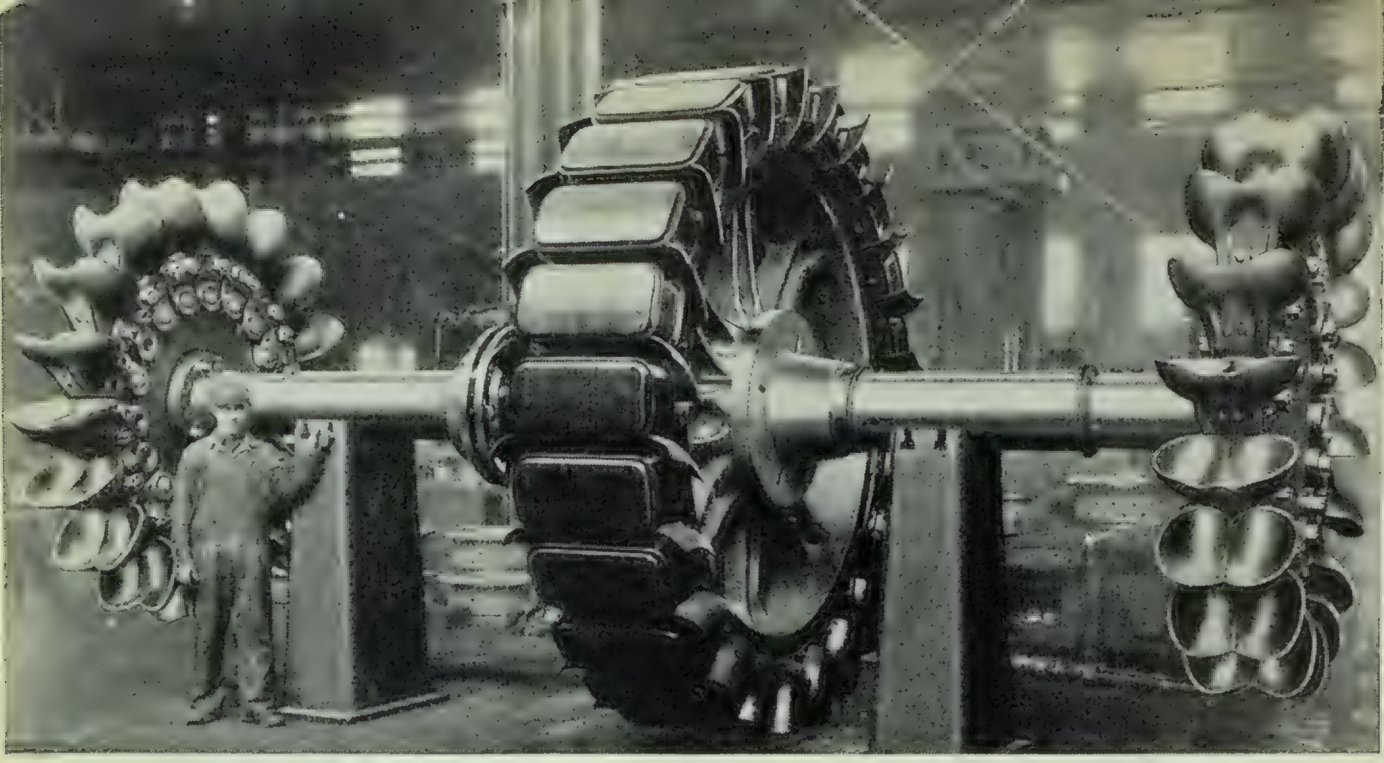


FIG. 343. These two huge Pelton wheels are attached to the axle of an electric generator. With water falling from a height of 700 feet they will turn the armature at a speed of 300 revolutions a minute to produce 3000 horse-power. (Allis-Chalmers photo)

Usually the first step in harnessing the energy of a stream is to build a dam across a large river, as was done on the Bow River west of Calgary, Alberta. Such a dam holds back the water and creates an artificial lake and a waterfall. Then, as the water drops from the top of the lake to the lower side of the dam, it gives its potential energy to the wheel. In other places, as at Niagara and in the mountains of the West, there is a sufficient natural fall of the water. Dams are needed only to store water and to guide it into canals, tunnels, and pipes that carry it down to the wheels.

The water-wheels in modern power-plants are of two types, *Pelton wheels* and *turbines*. The Pelton wheel is a kind of undershot wheel that is most useful where water can be brought from a great height. On the rim of the wheel is a row of carefully curved "buckets" (Figure 343). The wheel with its buckets is placed inside a strong case. The water, under great pressure, is led into the case and shot against the buckets by a large nozzle, much like that of a garden hose. The shape of the Pelton nozzle is very carefully planned to give the greatest possible speed to the water. The moving water then gives almost all its motion to the wheel which turns at a terrific speed. As much as 85 per cent of the energy of the water is given to the wheel for doing work.

By far the larger number of modern water-wheels are turbines

(Figures 344 and 345). Water enters the turbine between guide blades fastened to the stationary part, or case. The guide blades direct the water against the blades on the wheel, or rotor. All the passageways for the water, as well as the guide blades and the blades of the rotors, are carefully curved and streamlined to make the turbine as efficient as possible. Some turbines are 95 per cent efficient. In most cases these large Pelton wheels and turbines are connected to electric generators. Thus the harnessed energy of the moving water is sent in the form of electrical current to the homes, factories, and office buildings where it is used.

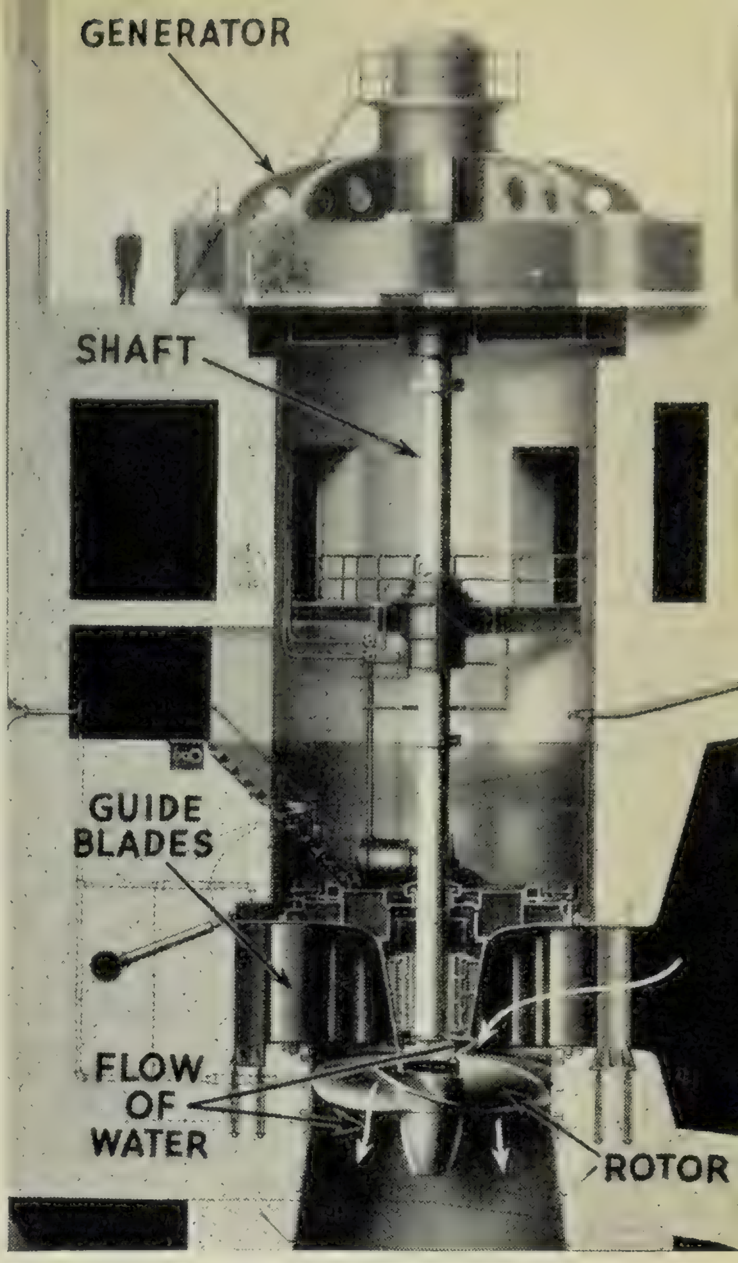



FIG. 344. A 13,500 horsepower turbine with the generator that it drives. The turbine wheel, or rotor, is the propeller-like device at the very bottom of the picture. Water enters the turbine from the dark space at the right, through the guide blades just above the rotor. Notice how small the man looks beside the generator. (Allis-Chalmers photo)

Only a small proportion of the water power that is available in Canada has been harnessed. You may wonder why all the water power is not harnessed, because it has such great advantages. Much of the water available for power is in mountainous regions far from railroads and cities. In such places there is little need for harnessed energy, and electric current cannot be economically carried over wires more than about 250 miles long. The second great disadvantage of using water power to generate electrical current is the cost of building the dams, pipe-lines, and power-plants.

*Self-Testing Exercises.* 1. Name two types of old-fashioned water-wheels and two types of modern water-wheels.

2. State three differences between the two kinds of modern water-wheels.

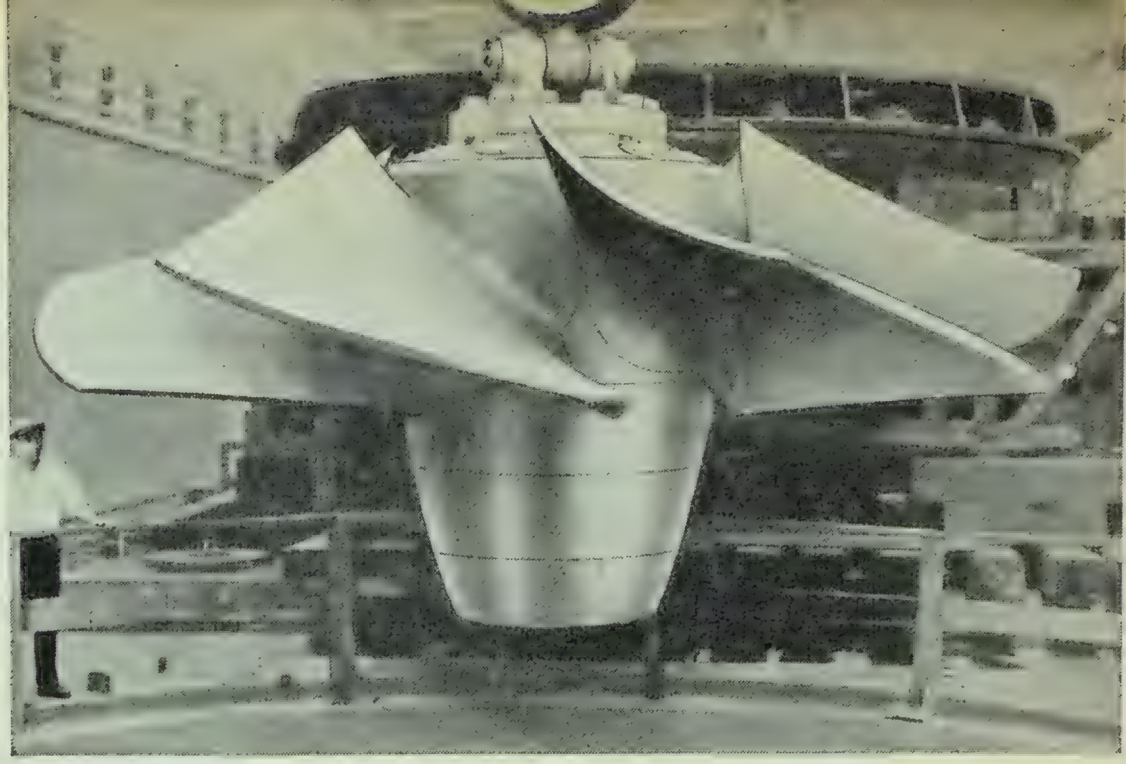


FIG. 345. Lowering a giant turbine rotor into the pit. Notice that in this rotor the blades can be adjusted so that the water will strike them at just the right angle to make the turbine operate most efficiently. (Allis-Chalmers photo)

3. How are turbines built to make them very efficient?

4. State two advantages and one disadvantage of using water power from a river to light a town and run factories on the banks of the river.

5. Why is only a small proportion of the water power in Canada now harnessed?

*Problems to Solve.* 1. Do you think that wind power or water power is more important in our country at the present time? Give reasons for your answer.

2. Compare the advantages and disadvantages of wind power and water power.

3. What interesting facts can you learn about the great water power-plants of this country? Choose one of the plants listed in Table 17, and learn all you can about it. Report to your class.

4. Build a working model of either an overshot or an undershot water-wheel.

5. How did water power influence the location of cities in the eastern part of Canada during the years when our country was being settled? See what you can find about this problem in history books and encyclopaedias.

6. Investigate any water power-plants near your home. Find out everything you can about them.

7. In a certain turbine the water falls 45 feet. The turbine is 90 per cent efficient and does 50,625 foot-pounds of work per second. How much water passes through the turbine in one second? (1 cu. ft. of water weighs 62.4 lb.)

FIG. 346. The story is that the jumping, chattering lid of a boiling tea kettle set James Watt thinking about the problem of harnessing the energy of steam. But the fact is that other men had thought of the problem long before Watt's time. Watt really began to think about steam engines while he was repairing a little model of an engine made by Thomas Newcomen. Watt was then a student at the University of Glasgow.

## 2. How do we measure power?

YOU HAVE OFTEN HEARD the term *horse-power* used in connection with such machines as an automobile or steam engine. In fact, you have read in Problem 1 about water-wheels that have more than 100,000 horse-power. Just what is a horse-power? And how do scientists find out how many horse-power a power machine has? Before you can understand what a horse-power is, you will need to get a clear idea of the meaning of the word *power*. Like many other words, power has two different meanings. We often speak of water power and of getting power from steam engines. In these cases, power means useful mechanical energy, or kinetic energy. It means almost the same thing as harnessed energy, or energy under control and ready to do work.

But scientists and engineers have a somewhat different meaning for this word. When they speak of the power of a machine, they are thinking of *the rate at which it can do work*; that is, the water-wheel that has the most power can do work faster than any other water-wheel. One of the important things that scientists and engineers do when they study anything is to measure it, if possible. They have learned a great deal about water-wheels and engines by measuring the power of these machines.

Whenever we wish to measure power, distance, weight, or anything else, we must have some unit with which to measure. The first unit of power was worked out by James Watt. About 1785 Watt needed a good "sales talk" to convince the mine owners of England that they should use his improved steam engines in the place of horses. He had to be able to tell them how many horses they could sell if they would buy one of his engines. To get the facts he needed, Watt measured the amount a horse could pull steadily and how fast it walked as it pulled. From his figures Watt calculated that a strong horse could do about 33,000 foot-pounds of work in a minute and keep it up steadily. Therefore Watt said that when an engine could do 33,000 foot-pounds of work per minute (550 foot-pounds per second), it was a one-horse-power engine.

The horse-power worked out in this way by James Watt became the standard unit for measuring power, and it has been in common use ever since. One horse-power is really a little more than the rate at which a horse can work all day. To work at the rate of one horse-power, a horse must pull with a force of 125 pounds and walk three miles per hour. A strong man running up stairs as fast as he can go produces more than one horse-power. It has been estimated that a sprinter in a 100-yard dash develops about eight horse-power at his greatest speed. But, of course, a man cannot work that fast for very long. A man can work steadily on the average at the rate of about one-tenth of a horse-power.

To calculate the horse-power of yourself, of an animal, or of a power machine, you need to know three facts: (1) the force that is exerted, (2) how far the force moved something, (3) the time that was required to move it that far. Let us calculate the horse-power used by a motor in lifting four people in an elevator up three floors. The force that lifts them must overcome their weight and, in addition, a small amount of friction. A *counterweight* is arranged to lift the elevator itself. We shall say that the force needed is 600 pounds. The elevator moves a distance of 25 feet in going from the first floor to the third. The amount of work done is thus 15,000 foot-pounds ($600 \times 25$). The time required is 12 seconds. The work done in one second is 1250 foot-pounds. Since one horse-power is 550 foot-pounds per sec-

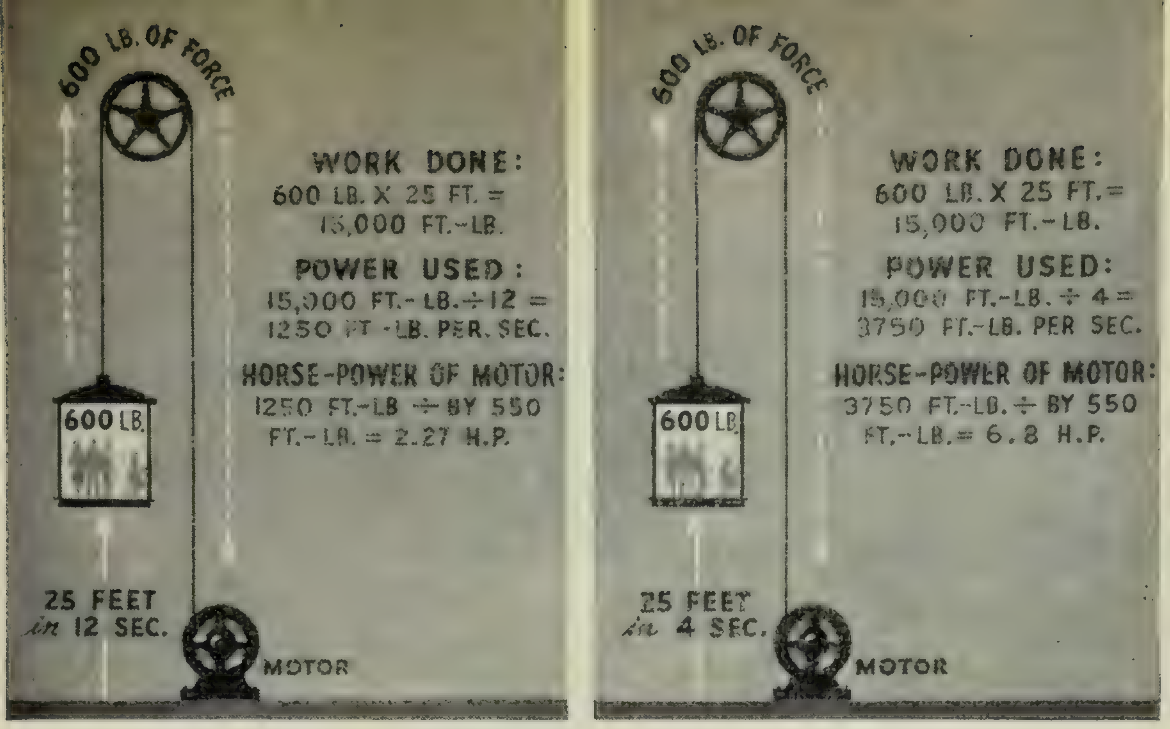



FIG. 347. These diagrams will help you understand how horse-power is calculated. Do the figuring for yourself, and be sure that you can explain exactly what the drawings show.

ond, the motor that lifts the elevator delivers a little more than two and one-quarter horse-power (2.27 H.P.).

This elevator moved quite slowly. Let us suppose that it is a high-speed elevator which moves three times as fast as before. Then the motor will need to work three times as fast, and therefore deliver about seven horse-power. Of course, in deciding how much power the motor should have, the engineers would need to know the greatest possible load the elevator would be called on to carry. Then they would take into consideration the friction of the pulleys and the gears. The motor that is used in any machine should be able to produce somewhat more power than is actually needed.

Scientists who have studied energy and power since the time of Watt have found that the horse-power is an inconvenient unit for measuring power. To fit their needs they use a small unit called the *watt*, in honor of Watt, and a larger unit called the *kilowatt* (1000 watts). Although we usually hear the term used in connection with electricity, any power can be measured in watts. One watt is equal to about 44 foot-pounds per minute. The power used by a 100-watt light-bulb is about the same as a 75-pound boy would use going upstairs at the rate of two steps per second. The kilowatt is often used by engineers in connection with power machines that drive electric generators. One kilowatt is about 1.34 horse-power. Therefore a 5000-kilowatt water-turbine would be rated as a 6700-horse-power wheel.

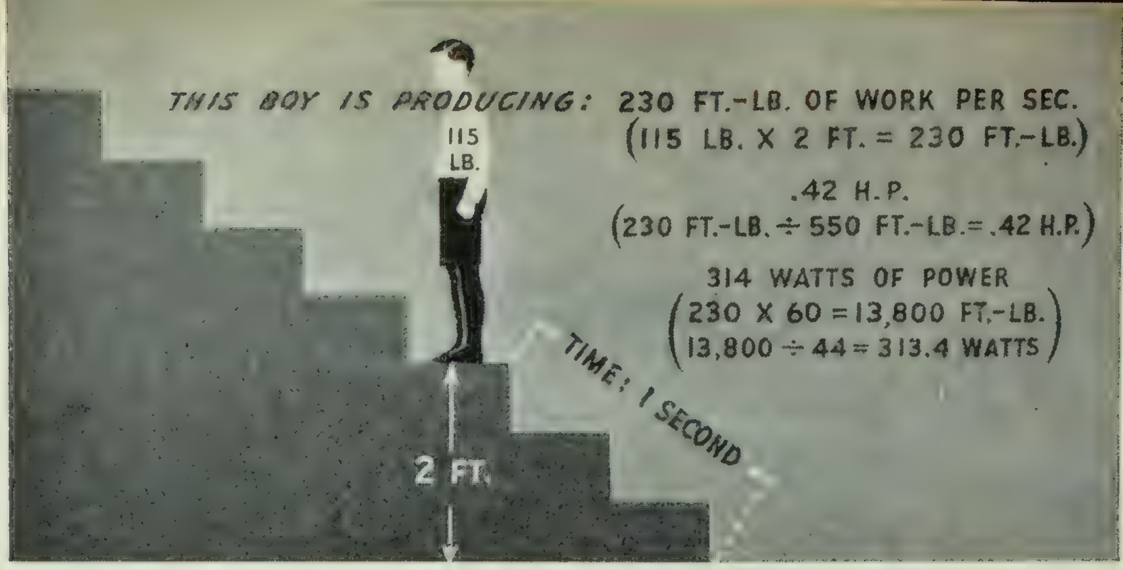



FIG. 348. Figure out for yourself the horse-power being used by this boy. How much horse-power will the boy use if he goes up the stairs to a height of 10 feet in 5 seconds?

*Self-Testing Exercises.* 1. Fill the blanks in the following statements in a way that will explain two meanings of the word *power:* (*a*) When we speak of using a gasoline engine for power, we mean that we will get ............ from the engine. (*b*) The power of a water-wheel is the ............ at which it can ............

2. What is a horse-power? A watt? A kilowatt?

3. What facts must a person have in order to figure the horse-power of a machine?

4. A gasoline engine was sold as a three-horse-power engine. How much work should it be able to do in a minute?

5. A load lifted by a ten-horse-power motor is 500 pounds. How many feet can the motor lift the load in one minute?

6. Many small motors for use in electric refrigerators and washing-machines are rated at one-fourth horse-power. How much work should such a motor do in a minute?

7. When a man works at the rate of one-tenth of a horse-power, how fast does he work?

*Problems to Solve.* 1. Find a stairway where you can do an experiment without disturbing anyone. (*a*) Find the time it takes you to walk up the stairs. Measure the height of the stairs and calculate the work you do in climbing them. Then find how much work you do per second. What fraction of a horse-power do you produce when you are walking up? (*b*) Repeat the problem for running up the stairs.

2. What fraction of a horse-power is required to operate a 550-watt electric iron?

3. A water-turbine has 50,000 horse-power. (*a*) How many foot-pounds of work does it do in a minute? (*b*) How many gallons of water could it pump to a height of one mile in one minute? (Count 10 lb. per gallon and 5280 ft. per mile.)

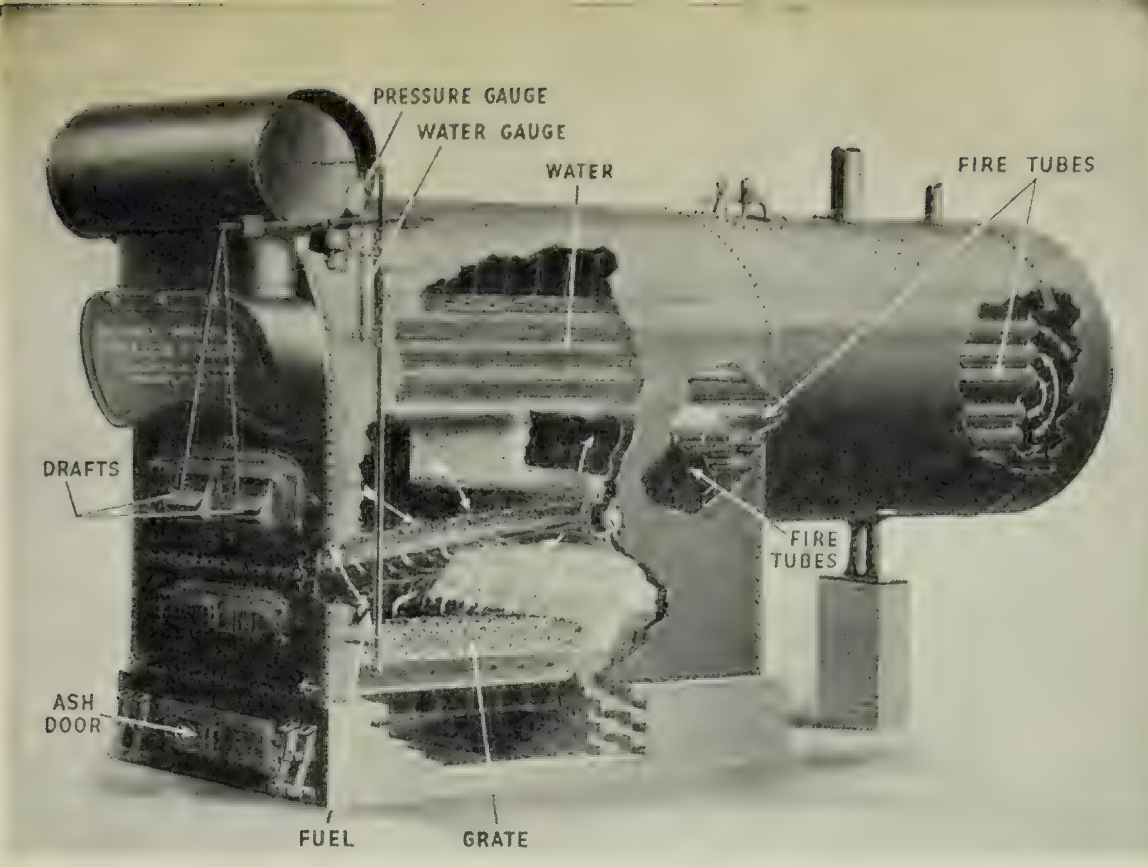


FIG. 349. Railroad locomotives use fire-tube boilers, built on the same principle as this one. Compare this boiler with the one shown in Figure 353. (Kewanee Boiler Co. photo)

## 3. How do we use steam to harness the energy of fuels?

HOW DOES STEAM RUN AN ENGINE? You have learned in your study of science that coal, like other fuels, contains a large amount of hidden energy, called chemical energy. You know, of course, that we buy coal to heat our homes and schools. But only a fraction of the coal mined is used for this purpose. Most of the remainder is used to run machinery. How can the chemical energy hidden in a fuel be made to turn the wheels of machines? Inventors studied this problem for 1800 years and finally solved it quite successfully about 175 years ago.

The first important step in harnessing energy through steam is to get the heat from burning coal into water so that steam will be made. To use as much of the heat as possible, boilers are arranged so that a great amount of water touches the steel tubes that receive the heat from the fire. One way to do this is to let hot gases from the fire pass through tubes surrounded by water. This type of boiler is called a *fire-tube boiler* (Figure 349). The kind of boiler used in the largest steam power-plants is usually a *water-tube boiler* (Figure 353). As the name tells you, the hot gases from the fire pass around steel tubes filled with water. In both of these types of boilers steam collects in the space above the water level.

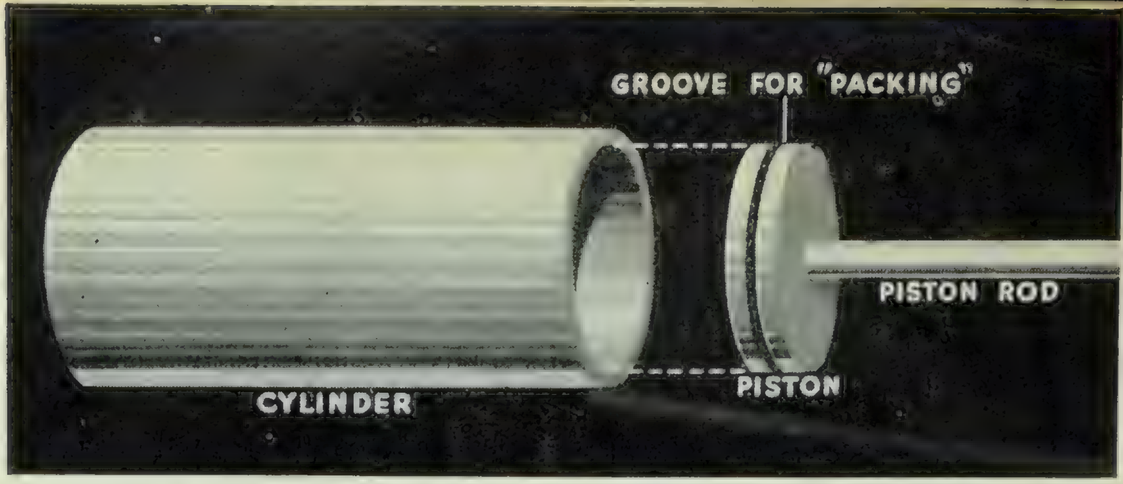



Fig. 350. The harness for the energy of steam—a cylinder and a piston. In the early days of the steam engine men found it very difficult to get the cylinders perfectly round and smooth and the pistons to fit tightly in them. Inventing a machine is only half the problem. Machines to make the machine must then be invented.

Have you ever heated water in a test-tube and let it push the stopper out? If so, you have seen a steam power-plant at work. One end of the test-tube was the boiler; the other was the cylinder. The stopper was the piston for the steam to push (Figure 351). The steam engine has a cylinder to hold steam while it works, and it has a piston that fits closely inside the cylinder (Figures 350 and 352). But an engine has several parts that your test-tube power-plant does not have. First, the piston is connected to a crank so that it will turn a wheel when the steam pushes it. Second, there are pipes and valves to let the steam into and out of the cylinder. To push the piston one way, the steam must go in on one side of the piston. To push it back again, the steam must go in on the other side.

Figure 352 shows a common type of engine cut open so that you can see how it works. The steam comes from the boiler through a pipe (1). It enters the *steam chest* (2) and goes past the *slide valve* (3). Then it passes through an opening into the cylinder. There the steam presses against all sides of the cylinder and against the piston (4). The piston is the only part that can move. Thus the steam pushes the piston to the right and turns the flywheel. Soon the piston stops because the crank will not let it go any farther.

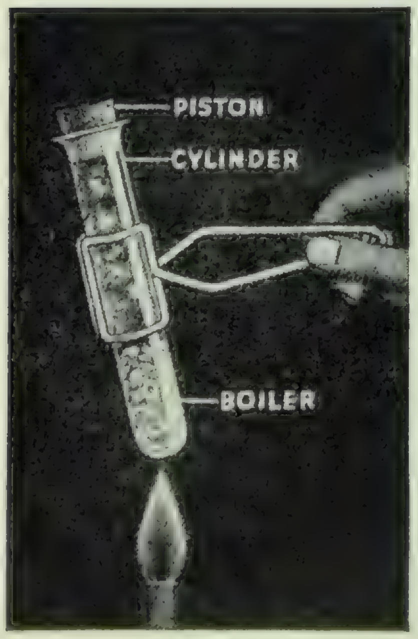



Fig. 351

Just before the piston stops the rods attached to the slide valve move the

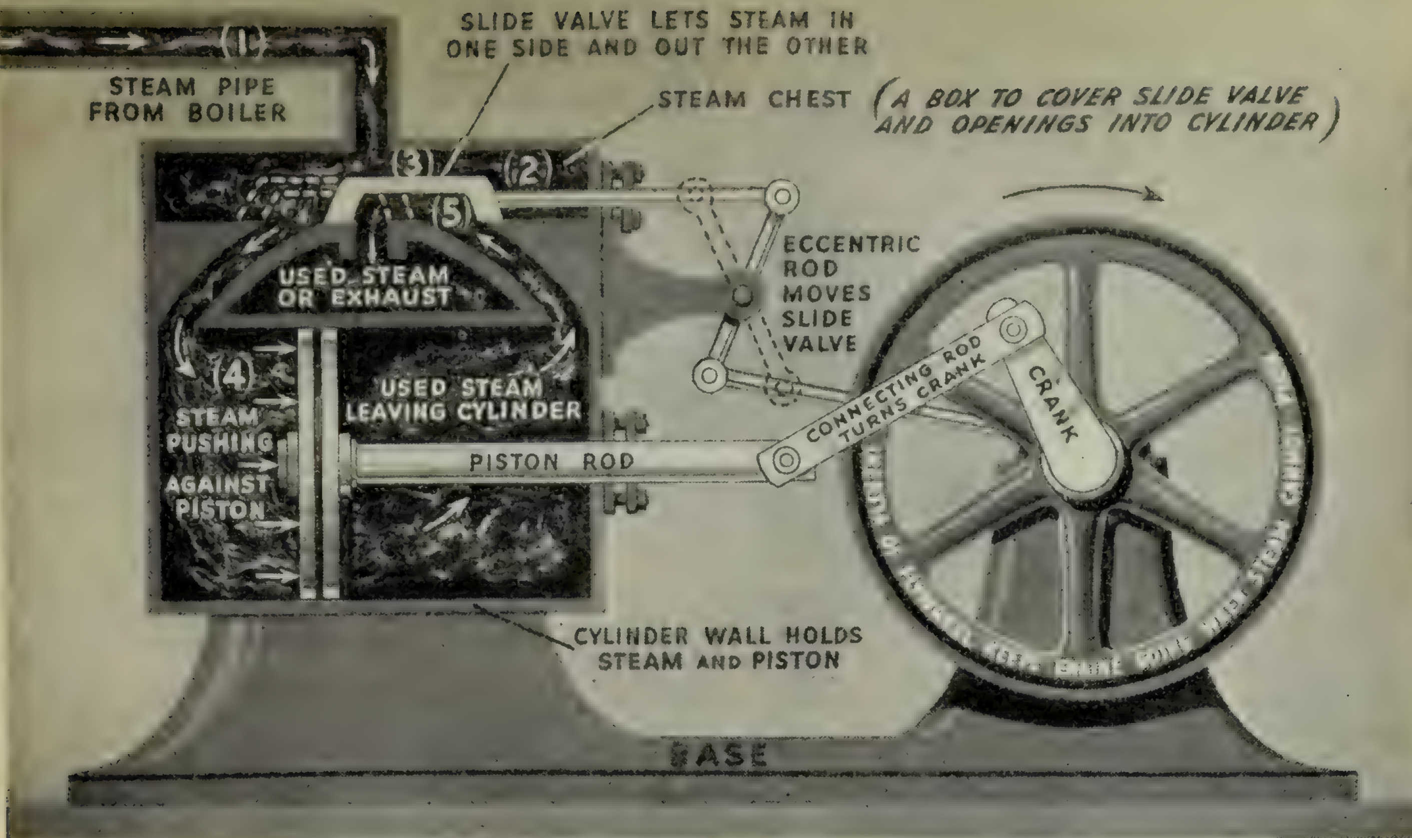



FIG. 352. How a steam engine harnesses energy

valve to the left to the position shown by dotted lines. Now the steam can escape from the left end of the cylinder and go out through the exhaust pipe (5). At the same time the steam from the boiler can go into the right end of the cylinder and push the piston back. When the piston reaches the left end, the slide valve changes, and again the piston is pushed to the right. This action occurs over and over again, sometimes very rapidly and at other times so slowly that you can count the motions of the piston rod. The connecting rod and the crank change the reciprocating motion of the piston rod into the rotary motion of the crank shaft and the flywheel.

There are two points where the piston cannot move the crank and flywheel no matter how hard it pushes. These points are at the ends of the cylinder when the connecting rod and the crank are in a straight line. These two places are known as the *dead points*. There the crank is said to be on *dead centre*. One important reason for having a flywheel is to keep the engine from slowing up or stopping on dead centre. The flywheel has much inertia. Therefore, when it has been started by a strong push of the piston, it keeps on turning and carries the crank past the dead points. The rods that move the valve may be attached to the engine in different ways. The common way is to have a small crank or eccentric on the crank shaft. This crank is arranged so that it moves the valve rods back and forth at just the right times.

The reciprocating steam engine is, however, very inefficient. The best of this kind can harness only about 20 per cent of the energy of the fuel used in the boiler. Gradually such engines are being replaced by steam turbines, about which you will learn in the next few pages.

*Self-Testing Exercises.* 1. Why is coal valuable?

2. What are the two main uses to which the energy of coal is put? For which one is more coal burned?

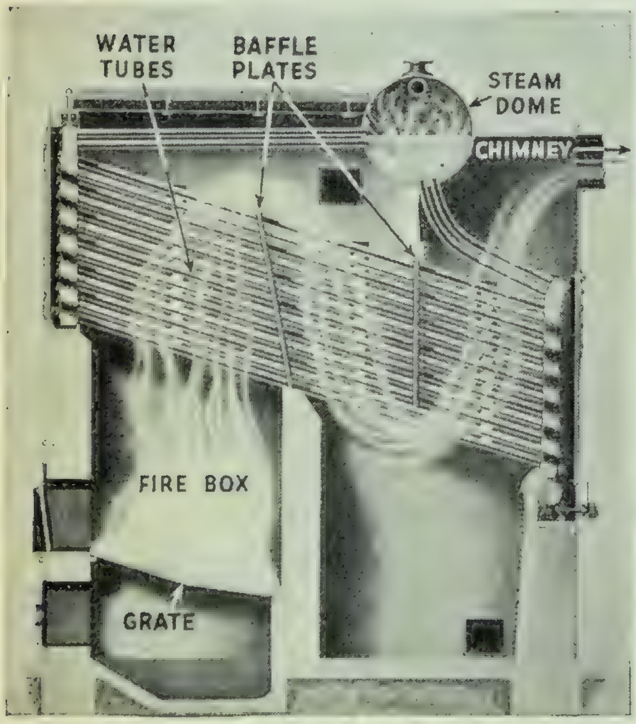



FIG. 353. A water-tube steam boiler

3. With your book closed, draw a simple diagram of a fire-tube boiler or a water-tube boiler. Use one color of shading to show where the hot gases go, another to show the water, and a third to show the steam. Write a paragraph that explains what your diagram shows.

4. Tell what each of the following does to help steam turn the flywheel of a steam engine: (*a*) piston, (*b*) piston rod, (*c*) crank, (*d*) slide valve, and (*e*) slide-valve eccentric.

5. Tell the story of some energy from the time it is in coal in a bin until it has changed into the kinetic energy of an engine wheel.

*Problems to Solve.* 1. If the slide valve shown in Figure 352 were in the position shown by the dotted lines, how would the other parts of the diagram need to be changed? Make a copy showing the changes.

2. Most steam engines are equipped with *governors* to regulate their speed. How does a governor work?

3. If possible, visit a railroad yard or other place where you can see a steam engine. Ask the man in charge to tell you what each part of the engine does.

4 Make a cardboard or wooden model like Figure 352. Make the slide valve and piston with their rods of separate pieces of material so that you can move them back and forth to help your classmates understand how a steam engine operates. Perhaps you can arrange a crank and crank shaft that will turn and move the slide valve at the proper time.

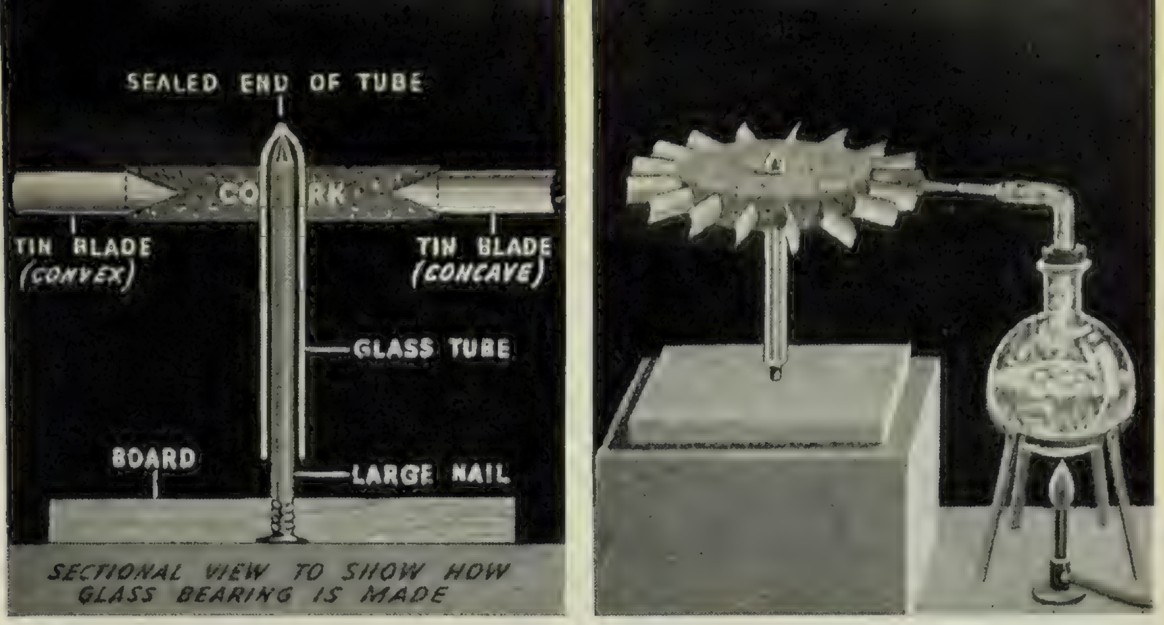


FIG. 354. How to make a model steam turbine

HOW DO STEAM TURBINES WORK? Go into any really modern steam power-plant and ask to see the engines. The engineer will probably lead you to a large painted "box." If you insist on seeing the engine, he will tell you that this box is a *steam turbine*. He will also tell you that it is doing the work of 1000 horses in a space about one-tenth as large as a reciprocating engine would need and less than would be needed to care for three horses.

When you learn these facts about the innocent-looking "box," you begin to get interested in it. Nothing very much seems to be happening, except that a kind of steady roar fills the space around you. Looking more closely, you see that a large shaft that seemed to be standing still is really spinning with terrific speed. What makes it spin? Inside the painted metal box is a kind of windmill run by steam. Steam from a boiler enters the box and rushes from one end to the other at speeds up to 1000 miles an hour. The blades of the "windmill" change the energy of this rushing steam directly into rotary motion. You can probably understand the principle of a steam turbine most easily by seeing a model turbine run.

*Experiment 79.* HOW DOES A STEAM TURBINE WORK? Make a model steam turbine as shown in Figure 354. A large cork or cylindrical piece of wood can be used for the wheel. Cut the blades from a tin can and push them into knife cuts in the rim of the wheel. When the wheel is ready and turns very easily, heat water in the flask to make steam. *Be Careful. Very high pressure in the flask may blow the stopper out and scald someone with the steam and hot water.* Avoid this danger by pressing the stopper in only lightly and using a low flame after the water begins to boil. If your wheel is properly made, the steam from the nozzle should make it spin rapidly.

A turbine like yours was made 300 years ago, before steam engines were invented. However, it never developed very much power; it was considered to be nothing but an interesting plaything. In 1889 Carl De Laval, a Swedish inventor and engineer, wanted to make steam spin a part of a cream separator very rapidly. To do this, he made a wheel very much like yours and arranged several nozzles to send steam against the blades, as shown in Figure 355. By various improvements he soon made a wheel that turned 30,000 revolutions per minute. Today you can see a steam turbine of this type somewhere on the side or top of every large steam locomotive. Usually there is a little cloud of steam escaping from it. It is generating electricity for the lights of the locomotive.

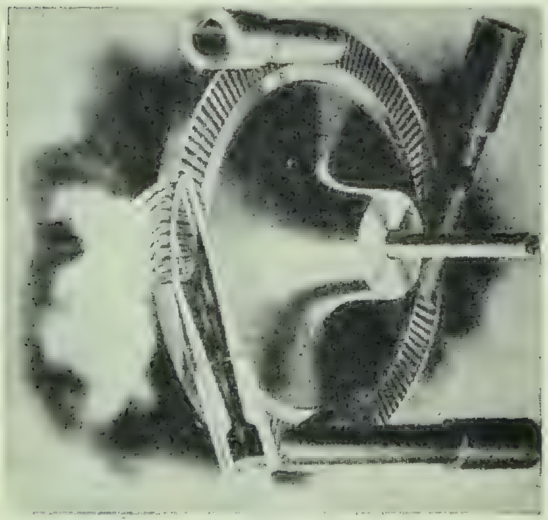


FIG. 355. A De Laval turbine

However, the large turbines in power-plants and ships are made somewhat differently. Instead of having a single row of blades on a wheel the shaft carries many rows of blades (Figure 356). The steam strikes the smallest row of blades from the side. Then a row of stationary blades fastened to the cover of the wheel turns the steam so that it gives the second row of moving blades a push. The steam then passes row after row of stationary blades and moving blades until it has lost almost all its energy. From the case of the turbine the steam goes into a cool place where it is condensed. The water is then sent back to the boilers to be used over again. The turbines that are used to drive a modern ocean liner have more than a million blades. The edge of the wheel travels at a rate of more than 400 miles an hour, and it is so close to the case that uneven heating will make the blades touch the case and be ruined. Several turbines have been built that produce more than 200,000 horse-power from each single machine.

Turbines have several advantages over reciprocating engines. They take up much less space in proportion to the power they

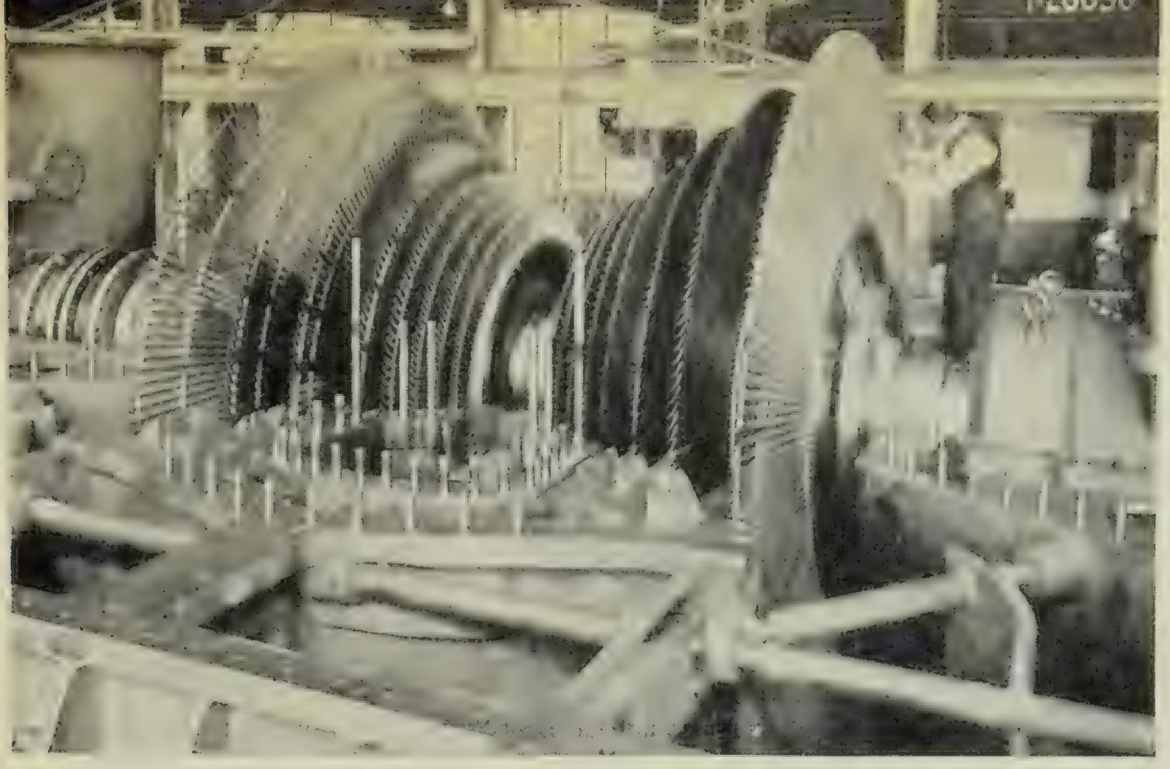


FIG. 356. Here is the inside of a giant steam turbine with sixteen sets of moving blades. The biggest wheel of blades is about fifteen feet in diameter. The steam enters this turbine at the centre and moves toward both ends through the blades. (Westinghouse photo)

produce, and they run more smoothly. They are more efficient, for a good turbine power-plant uses about 28 per cent of the energy of the fuel. They produce rotary motion directly from the steam; therefore there are fewer moving parts and less friction. However, as you would expect, there are also certain disadvantages of turbines. They cannot well be run slowly. They run so fast that gears must be used to reduce their speed for pumps and ship propellers. Successful turbines are much more difficult to build than engines. The slightest flaw may cause a huge machine to tear itself to pieces and do a hundred thousand dollars' worth of damage. Turbines cannot be reversed, while an ordinary engine runs just as well backward as forward. Can you imagine how ships and locomotives driven by turbines can be reversed?

*Self-Testing Exercises.* 1. For what purposes are steam turbines most useful?

2. How does a large turbine use the steam more than once?

3. (*a*) Explain three or more advantages steam turbines have over steam engines. (*b*) Explain two or more disadvantages that they have.

*Problems to Solve.* 1. Make a list of the problems you think the inventors needed to solve in producing efficient turbines.

2. Where does the electric-power company in your locality obtain its electric power? Perhaps you can get permission to visit the plant and learn how the generators are driven.

## 4. How is the energy of fuels harnessed by internal-combustion engines?

YOU HAVE SEEN THAT STEAM POWER-PLANTS harness energy in two steps: (1) The fuel is burned to make steam. (2) The steam runs an engine or turbine. This plan requires, in addition to the engines, heavy boilers filled with water and a supply of fuel. Such engines can usually be used only where a heavy power-plant is possible: in stationary power-plants, in steamships, and in locomotives. Inventors long ago saw that if they could release energy and harness it all in one step, they would have a much lighter harness. What they needed was an engine that burned the fuel in the cylinder instead of in a separate boiler.

From about the year 1800 inventors were hard at work on the problem of making an engine that would burn the fuel inside itself so that it would not need a heavy boiler. By 1880 a few engines were being made that burned the fuel in the cylinder. Because they burned fuel inside themselves, they were called *internal-combustion engines*. Today the wide use of automobiles, trucks, tractors, and aeroplanes shows that this new light harness for using the energy of burning gas is successful. Watt's early steam engine weighed nearly a ton for every horse-power of energy it harnessed. But a ton of metal in an aeroplane motor produces 2000 horse-power. About three-fourths of all power produced on this continent is obtained from internal-combustion engines.

HOW CAN A FIRE PRODUCE A PUSH? To understand how internal-combustion engines work, you must first learn how fuel can be burned in a closed place and how it can give a push because it is burning. A simple experiment will show us how this is possible.

*Experiment 80.* HOW DOES A MIXTURE OF GAS AND AIR BURN? Obtain a friction-top tin can about three inches in diameter and five inches high. With a large nail make a hole in the lid and one in the side near the bottom. Enlarge the hole in the side until it is about three eighths of an inch in diameter. Fill the can with illuminating gas through a rubber tube leading to the hole in the side. Turn off the gas. Remove the tube and immediately bring a lighted match to the hole in the top. The gas should catch fire and burn quietly.

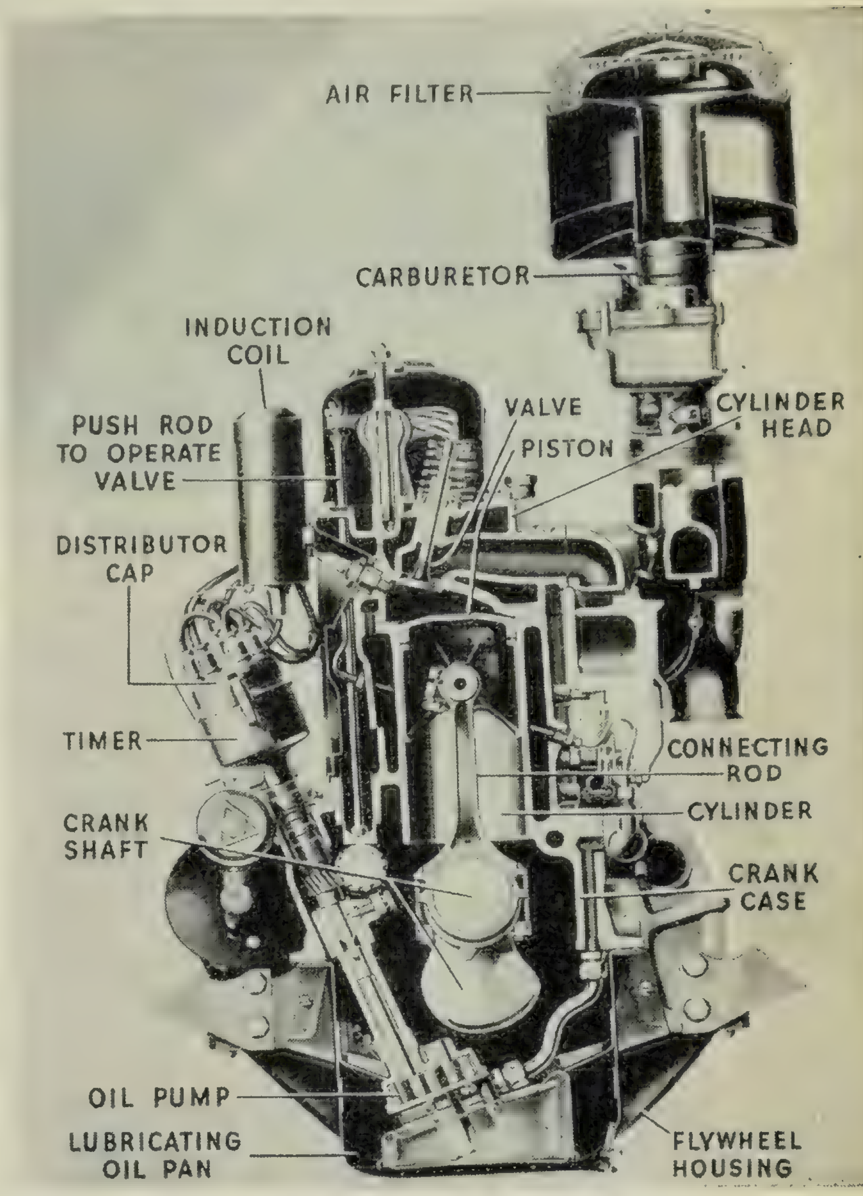



FIG. 357. A cut-away view of a modern automobile engine. This is known as the *over-head valve* type of engine. Find out how the valves are arranged in other types of engines. Also find out the purpose of any of the labelled parts that you do not know about. After you have studied the next few pages, examine this picture again to see how many of the parts you can explain. (General Motors photo)

Stand back several feet and watch the flame. Air is entering the hole at the side of the can and mixing with the gas. How does the color of the flame change as the percentage of air increases? What happens just as the flame seems about to go out?

The tin can in this experiment is really a crude internal-combustion engine. The can is the cylinder; the lid is the piston. Gas is the fuel that contains the chemical energy to be released. When just the right percentage of oxygen became mixed with the gas in the can, you probably had what you would call an explosion. This explosion was only a very rapid burning of all the gas that was left in the can. The chemical energy of the fuel changed to heat energy in the gases in the can. The gases include much air mixed with carbon dioxide ($CO_2$) and water vapor ($H_2O$) from the burning fuel. See Unit 4, pages 106-109.

The heat made the molecules of these gases fly in all directions with much greater speed. In other words, the heat made the gases expand very quickly. The result was that the can lid flew off with a bang. The chemical energy of the fuel had been changed into the kinetic energy of the moving lid (or piston).

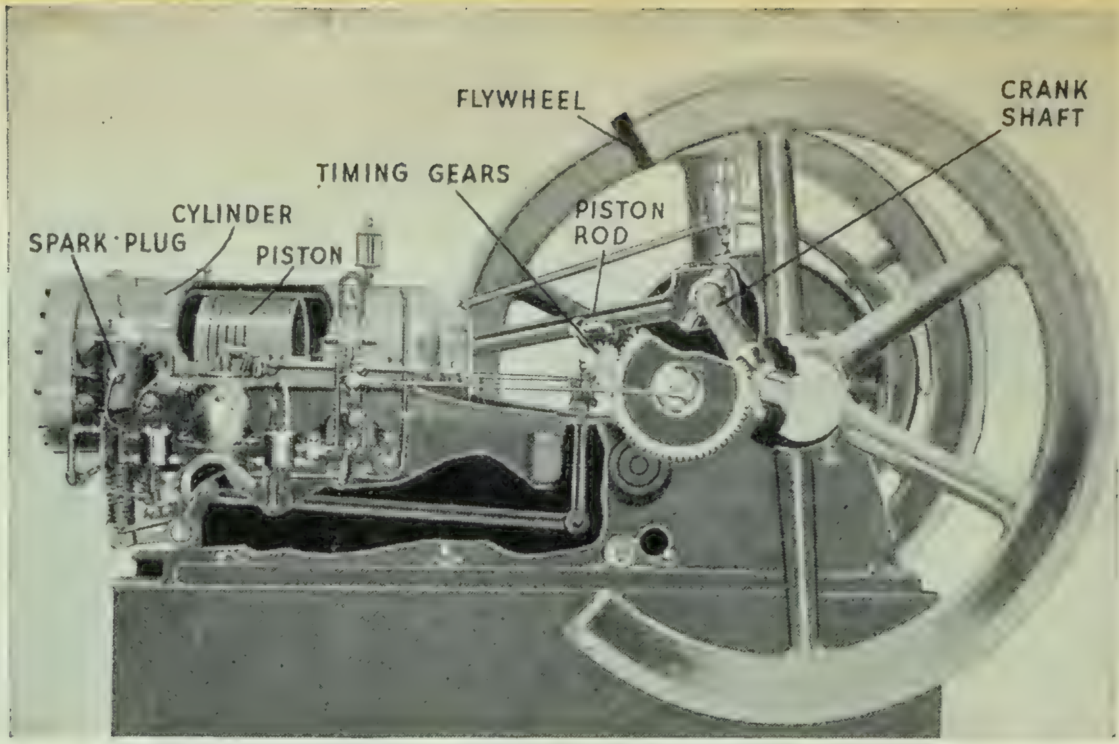



FIG. 358. The parts of a simple one-cylinder gasoline engine

Notice again what was done to make the fuel push off the lid: (1) You got the right mixture of air and fuel in the can. (2) The mixture was ignited by the flame. All internal-combustion engines do these same things. In addition, they compress the mixture to get more energy out of it, and they let out the burned gases to make room for a new mixture.

HOW DOES THE ENERGY OF BURNING FUEL RUN A GASOLINE ENGINE? Like a steam engine, a simple gasoline engine has a cylinder, piston, crank, crank shaft, eccentrics, and a flywheel. Find these parts in Figure 358. In addition, the gasoline engine needs two parts that a steam engine does not have: (1) It must have a way to mix the gasoline with the air. (2) It must have a way to ignite the gasoline at the right time. The *carburetor* mixes air and gasoline in the right proportions, and an electric spark sets the mixture on fire.

Let us now follow some gasoline into a one-cylinder gasoline engine and see what it does and how it gives its energy to the engine. Look at Figure 359 to help you understand what happens. To start the engine, the crank shaft must be turned. This may be done by hand (with a crank) or by an electric motor. Let us suppose that the piston is at the top of the cylinder.

(1) INTAKE STROKE. As the crank shaft begins to turn, an eccentric pushes the *intake valve* open. Then the piston moves downward. This leaves a partial vacuum in the cylinder. Air-pressure from the outside forces air in through the carburetor. As this air goes rapidly past nozzles in the carburetor, it takes with it the right amount of gasoline in the form of vapor, or a fine

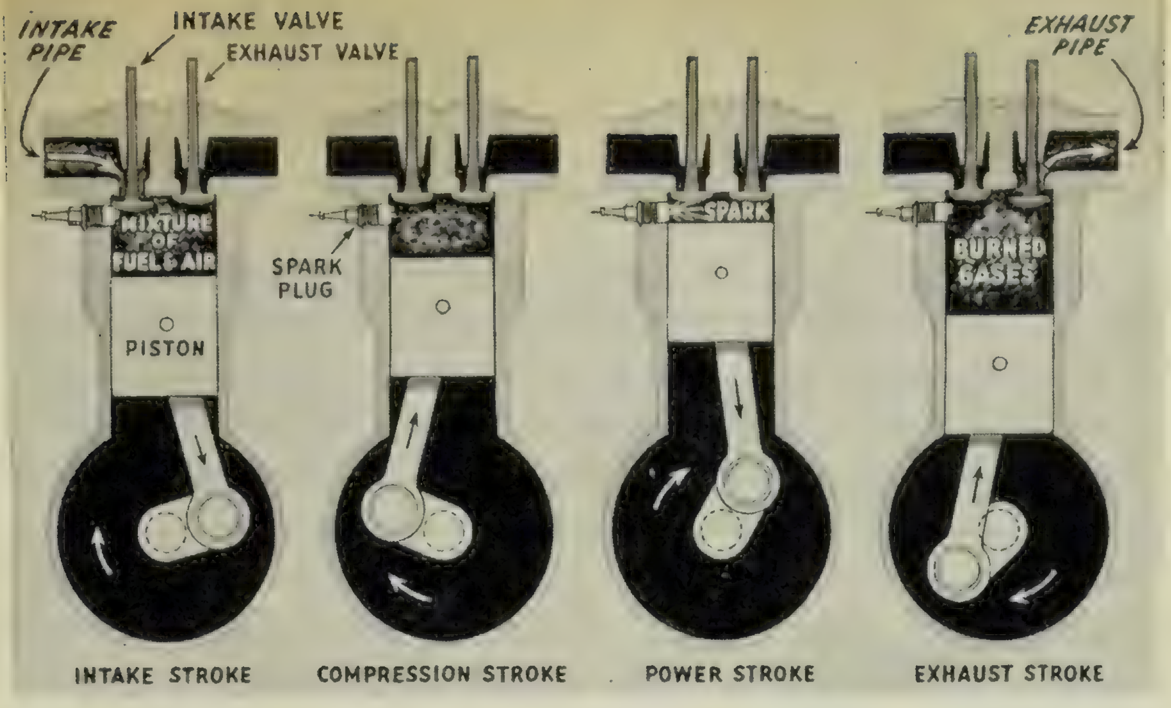



FIG. 359. How a gasoline engine harnesses energy. Be sure that you can explain what happens during each stroke.

spray. Just as the piston reaches the bottom, the intake valve closes. The *intake stroke* has been completed.

(2) COMPRESSION STROKE. On its way up, the piston presses the mixture of gasoline vapor and air into about one-seventh of the space it filled at first. When the piston reaches the top, it has finished the *compression stroke*.

(3) POWER STROKE. Just as the piston stops rising and starts down, an induction coil and other electrical devices make a hot spark leap the gap between the two wires in the spark plug. This spark sets the gasoline on fire, and it burns with great rapidity. The gases in the cylinder get very hot, and their pressure goes up to hundreds of pounds per square inch. Therefore the hot gases give the piston a tremendous push on its way down. The crank shaft and flywheel start turning rapidly. They have received kinetic energy from the burning of the fuel! The *power stroke* has occurred!

(4) EXHAUST STROKE. As the piston reaches the bottom of the cylinder with the hot gas against it, the *exhaust valve* opens, and the hot gases shoot out through the exhaust pipe. If the exhaust is open to the air, there is a loud bang. Usually, however, there is some kind of a *muffler* to let the gases out more quietly. The inertia of the flywheel and the crank shaft keep them turning, and they push the piston upward. This fourth stroke of the piston sweeps the remainder of the burned gases out of the cylinder. Then the exhaust valve closes, and the *exhaust stroke* has been completed.

However, the engine does not stop. The spinning flywheel and crank shaft open the intake valve and carry the piston down on a new intake stroke and up on a compression stroke. Then there is another push during the second power stroke. Our engine is running! It is getting the energy to run directly from the gasoline. The series, or *cycle*, of four strokes is repeated for every push the piston gets. Because of this method of operation, the ordinary gasoline engine is said to be a *four-stroke cycle* engine or, for short, a *four-cycle* engine. A somewhat different kind of engine has a two-stroke cycle; every downward stroke is a power stroke. Many two-stroke cycle (or two-cycle) engines are used on motorcycles, outboard motor-boats, washing-machines, and home electric generating plants.

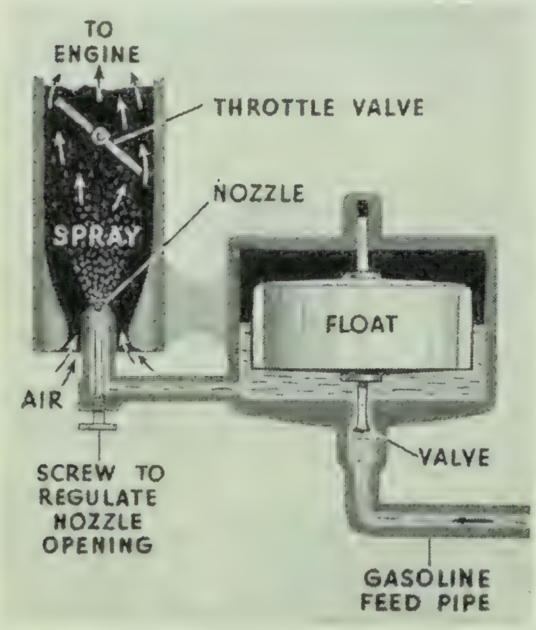



FIG. 360. This simplified drawing of a carburetor will help you understand how the carburetor works.

As you have seen, the piston of a four-stroke cycle engine gets a push only once in four strokes. As a result, the power from a single cylinder is rather irregular, and the flywheel must be quite heavy to smooth out the jerks. To get more power and an even flow of power, most internal-combustion engines have four or more cylinders. Six and eight cylinders are now most common in automobile engines. Twelve-cylinder automobile engines and thirty-six cylinder aeroplane engines are not at all uncommon.

As you can easily understand, the parts of the gasoline engine that you have seen at work must be helped by many other parts to keep the engine working successfully. A modern automobile engine has at least four systems of helping parts. The first is the *fuel system*. A pipe leads from the gasoline tank to a fuel pump attached in the pipe line near the carburetor. The pump keeps a little tank in the carburetor full of gasoline all the time. Usually there is a little cup and screen between the gasoline tank and

the pump to remove water and dirt from the fuel before it reaches the carburetor.

An *electrical system* serves several useful purposes. Most important, of course, is the production of a spark in each cylinder at the right moment. A sixteen-cylinder motor may run at the rate of 3000 revolutions per minute. In that time there must be 24,000 separate fires started in the cylinders, each one at just the right time. A *distributor* with wires sends electricity to each spark plug at the proper time. In addition, the electrical system has a *starting motor* to start the gasoline engine, a generator to make the electric current while the engine is running, and a storage battery to furnish current when the engine is not running.

All the moving parts of an engine must be well oiled to keep them from wearing out. Oil is also very important to make the pistons air-tight in the cylinders and to reduce the wear on the piston and on the walls of the cylinder. The *lubrication system* keeps the engine oiled. Its main parts are: a reservoir of oil in the bottom of the engine, a pump to force oil throughout certain parts of the engine, and pipes leading to all the parts that need oil.

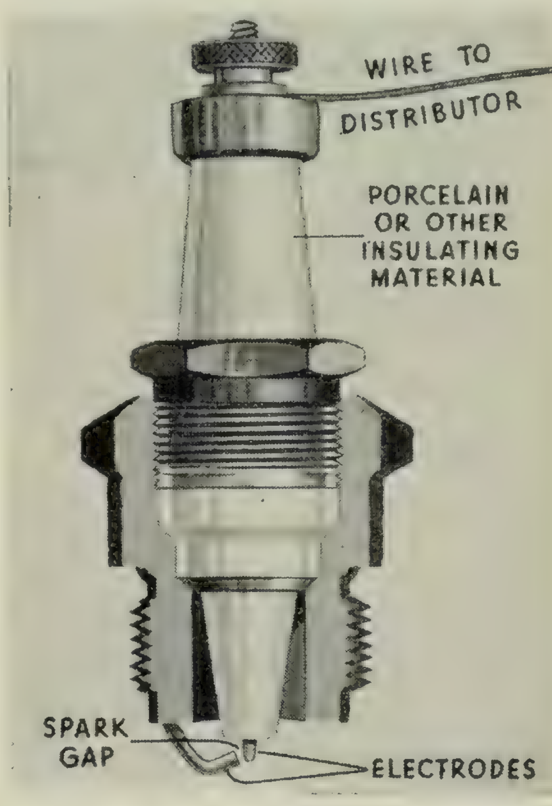



FIG. 361. The parts of a gasoline-engine spark plug

You have seen that the burning of gasoline in the cylinders produces very high temperatures. Some of this heat is used in pushing the pistons, but no one has found a way to use all of it. If this extra heat were left in the engine, the cylinders would soon get red-hot and be ruined. To prevent such damage is the work of the *cooling system*. A hollow space around each cylinder, the *water jacket*, is filled with water. A pipe leads hot water from these water spaces to many copper tubes in the *radiator*. A fan

located behind the radiator keeps the hot air moving away, and a water pump keeps the water circulating through the radiator and the engine.

*Self-Testing Exercises.* 1. Why is a gasoline engine called an internal-combustion engine?

2. Write down from memory the four strokes of a piston in a gasoline engine. After each one tell briefly what happens during the stroke.

3. (*a*) During which stroke or strokes must the intake valve be open? (*b*) During which stroke or strokes must the exhaust valve be open? (*c*) During which stroke must both be closed? In each case tell why.

4. Why is there greater pressure on the piston of an internal-combustion engine during the power stroke than during the compression stroke?

5. What advantages are there in having several cylinders in an automobile rather than one?

*Problems to Solve.* 1. Examine an automobile engine. Make a list of the important parts you can identify. Also make a list of the parts you find but whose use you do not understand. If you cannot name them, you may describe them briefly or tell where they are located.

2. (*a*) What advantages would a gasoline delivery truck have for milk delivery to city homes? (*b*) What advantages would a horse-drawn truck have?

3. (*a*) How many pushes does the piston of a one-cylinder steam engine receive during one revolution of the crank shaft? (*b*) How many cylinders must a gasoline engine have to get the same number of pushes?

4. Make a special study of one of the following and report to your class: (*a*) two-stroke cycle (two-cycle) gasoline engine, (*b*) aeroplane engines, (*c*) the cooling system of an automobile, (*d*) the lubricating system of an automobile, (*e*) uses of gasoline engines, (*f*) tractors and their uses, (*g*) the ignition system of an automobile, (*g*) kinds of motors used in aeroplanes.

HOW DOES A DIESEL ENGINE WORK? Have you seen a modern streamlined train thundering along the track faster than most steam trains go? Many of these trains are driven by Diesel engines, and Diesel engines are also used in small power-plants,

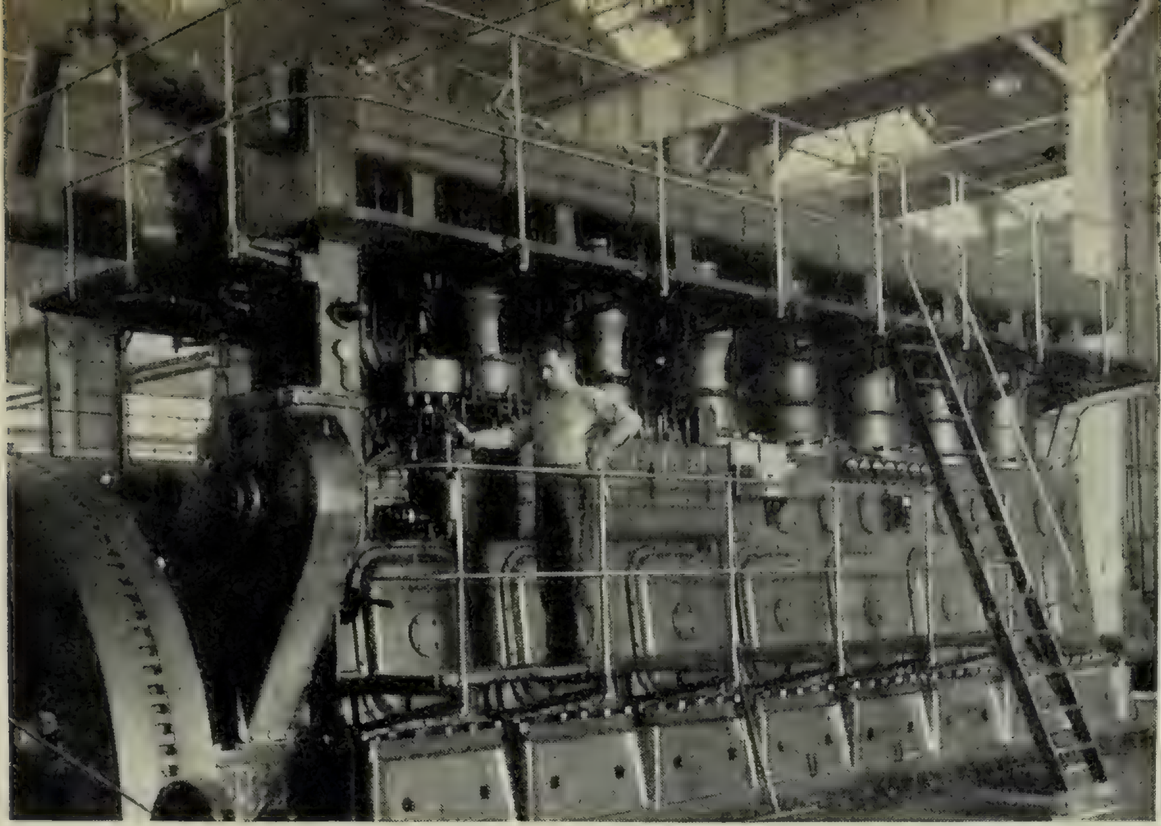


FIG. 362. An eight-cylinder Diesel engine in the power-and-light station at Russell, Kansas. This giant engine can furnish 1600 horse-power. (Nesmith and Associates photo)

trucks, tractors, and ships. Watch for a big motor truck with a pipe sticking up above the truck near the front. It is probably a Diesel-motored truck. You can often smell the burning oil. Diesel engines have even been put in aeroplanes. What are Diesel engines, and how do they work?

About 50 years ago Dr. Rudolph Diesel, a German scientist, got the idea that he could make an internal-combustion engine that would work without spark plugs. About 1897 he produced one that was successful. This kind of engine is much like the ordinary gasoline engine, except that it does not have spark plugs or a carburetor. It burns very cheap kinds of oil, and to do the same amount of work, it uses fewer gallons of fuel than a gasoline engine. A ton of oil burned in a Diesel engine does as much work as four tons of coal burned in a steam locomotive.

The Diesel engine gains these advantages through two important features: First, the air that enters the cylinder during the intake stroke is compressed into about one-fourteenth of the space it filled at first. (You remember that a gasoline engine compresses its vapor to only about one-seventh.) When air is compressed, it becomes warm. The very great compression in the Diesel engine cylinder causes the temperature of the air to rise to more than 800° F. Second, just as the piston reaches the top of its stroke, a small but very powerful pump sprays a tiny bit

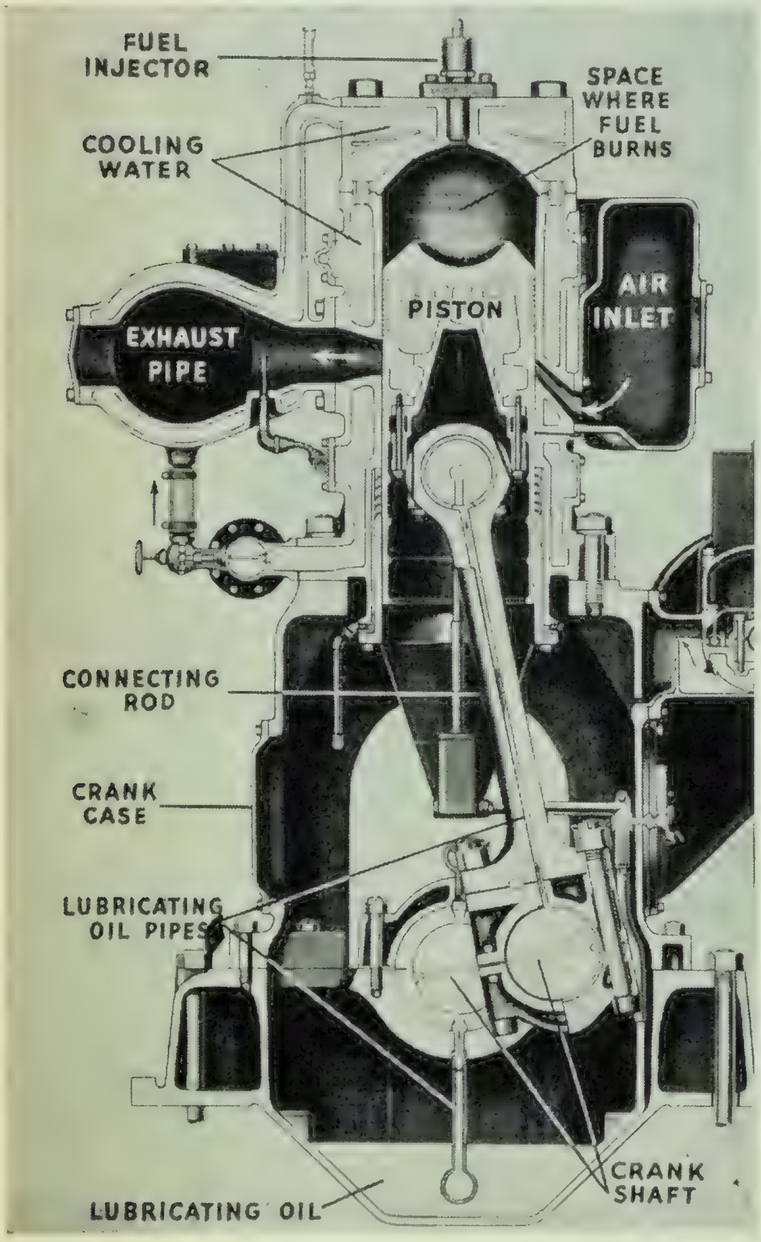



FIG. 363. A cross-section view of a Diesel engine. Compare it with Figure 357 to see how much alike the Diesel and the gasoline engines are. In this engine the piston opens and closes the intake and exhaust openings. (Fairbanks-Morse photo)

of oil into the hot air. Almost instantly the oil is vaporized and begins to burn. The heat from the burning oil expands the air and makes the pressure in the cylinder head still higher. This, together with the expansion of the burning oil vapor, drives the piston down during the power stroke.

Diesel engines are usually much heavier than gasoline engines, but they burn such cheap fuel and so little of it that they are widely used on trucks, tractors, and in power-plants. They are also being used in locomotives because they do not need to stop so often for fuel and water. As you know, a Diesel engine uses only one-fourth as many pounds of fuel as a steam engine of the same power.

From what you have just read, you can see that internal-combustion engines have a number of advantages over steam power-plants. They are very much lighter to carry around, and they use a convenient form of fuel. They also harness a higher percentage of the energy in the fuel. Small internal-combustion engines are much more efficient than small steam engines. The smaller the steam engine, the less efficient it is. But this is not true of internal-combustion engines. Gasoline engines are about 30 per cent efficient, while Diesel engines may be 38 per cent efficient. In addition, they can be started and brought to full speed quickly, instead of waiting a long time to "get up steam."

On the other hand, internal-combustion engines must be very exactly adjusted, or they will not run at all. Most internal-combustion engines cannot run backward. To reverse the direction of their force, a complicated set of gears is necessary. They tend to "die" if an overload is put on them, while a steam engine just keeps on pulling. From their wide use you can see that for certain purposes the advantages far outweigh the disadvantages.

*Self-Testing Exercises.* 1. (*a*) When is fuel put into the cylinder of a Diesel engine? (*b*) How is the fuel put in?

2. How is the fuel ignited?

3. State two other differences between Diesel engines and ordinary gasoline engines.

4. State three reasons why internal-combustion engines are used instead of steam power-plants for automobiles.

*Problems to Solve.* 1. Read in some reference book the story of Dr. Rudolph Diesel's life and of his experiences with his engines.

2. What do you think is the reason that gasoline engines rather than Diesel engines are used in automobiles?

## ¶ 5. What sources of energy will we use in the future?

WHAT IS THE REAL SOURCE OF THE ENERGY THAT RUNS OUR MACHINES? You now understand how man has gone out into the world and harnessed the energy he found there. He has harnessed the energy of the wind with sails and windmills. The water of streams running down to the sea turns his giant water-wheels. Energy from fuels runs his steam power-plants and internal-combustion engines. But have you seen that all the energy harnessed by these machines comes from one real source? Let us first see where the wind gets its energy. What makes it blow? The wind blows because the air at some place has become warmer than at some other place. Cool, heavy air pushes the warmed air up. The current of air moving along the earth is the wind. What starts the wind blowing and keeps it moving? It is really the sunlight warming the earth that makes the wind blow. The energy of the wind, then, comes from the sun!

And the water! Where did it get its energy? It has potential

energy because it is lifted up high above the level of the ocean. It can do work running down again. The water was evaporated by the heating effect of the sunlight. Then the wind blew the water vapor to great heights, from which it fell on the highlands. The energy for our water power also comes to the earth in the sunlight.

You have probably guessed the rest of the story already. The sunlight shone on the leaves of trees millions of years ago. The green leaves caught the radiant energy and stored it in the wood as chemical energy. Through long ages the wood was buried and gradually changed to coal. We mine the coal and use the energy. Similarly, the energy in petroleum came to the earth in sunlight. It was captured, probably by tiny green plants in the ocean. The plants were eaten by animals. The bodies of the tiny animals, buried in the sand and mud of the ocean bottom, each gave out a tiny amount of oil. This oil is the petroleum that collected in the great oil fields of the world. Thus the energy of the ancient sunlight, captured ages ago by green plants, takes us riding in the sunlight of today.

The winds will blow, and the rivers will run down to the sea so long as the sunlight and the mountains remain. Experts say that our coal supplies in America will not last for more than 4000 years. If we share with other countries and continue to use more and more ourselves, they will not last more than 1000 years. Coal is not being made today, and we are using up the store that was produced in past ages. About petroleum no one seems to know. Most people, however, believe that the oil fields will not last so long as the coal mines. What then?

WHAT ARE THE POSSIBLE ENERGY SUPPLIES OF THE FUTURE? Could we get more energy from the wind? That is quite possible. Someone has calculated that a wind blowing 30 miles per hour, a mile wide, and 100 feet deep could produce 100,000 horse-power. But what a forest of windmills we would have to put up! And how would we store such immense amounts of energy for the days when the wind does not blow?

Could we harness all the water power and use it instead of coal and oil? Only about one-fifth of the water power of Canada has been put to work. But even if it were, engineers

point out that there would be only half enough for the present power needs of the country. And much of the water power is so far away from cities that the energy cannot be transmitted to places where it is needed.

Could we harness the waves and the tides? Undoubtedly much energy is going to waste along the ocean shores. A British scientist estimates that the tides along the shores of Great Britain have 12,000,000 horse-power of energy. But no really successful plan of putting the tides to work has been invented. They come and go; so a power-plant that depended on them could not run continuously. Like wind power, a way of storing the energy would be needed. Like water power, tide power would have to be used within a few hundred miles of its source.

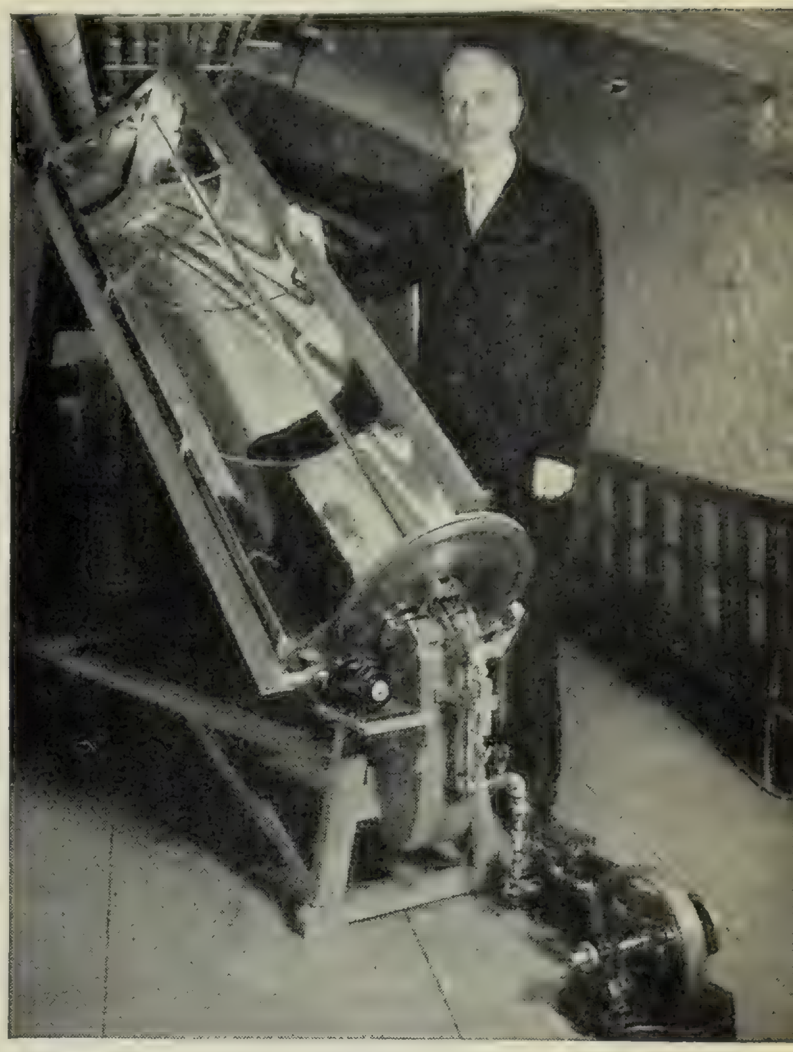


FIG. 364. This machine was invented to use the energy of the sunlight for running machines. It was actually able to run the small engine that you see in the lower part of the picture.

Can we find new supplies of fuels? When coal and oil give out, we will need to turn to fuel that grows each year. Corn stalks and straw, rapidly growing trees, and alcohol from grains and vegetables are possible sources of energy. In recent years there has been much talk of using alcohol in automobile engines to save gasoline. However, alcohol from grain costs much more than gasoline. And if the whole corn crop of the country were made into alcohol, there would be only half enough for our present needs.

Can the sunlight itself be put to work? Enough sunlight falls on the earth in one minute to drive all man's machines for a year. The light that falls on 200 square miles of Canadian prairie has sufficient energy to supply the whole of Canada. But how

can we capture this energy? That is the difficulty. Men have been at work on the problem for a long time. Some of them built great reflectors to heat oil and boil water. Engines have actually been run in this way. Some men are seeking a way to change light directly into electric current. They have really run a few tiny electric motors by such power. Other men are trying to have light carry on chemical changes that will store its energy. As yet, however, they have not been able to discover a method that works as well as the leaves of green plants.

What is the answer? No one knows. Certainly we are going right on using water power and coal and oil. Gradually, as fuel becomes more scarce and expensive, other kinds of fuel will be obtained from plants. Perhaps someone will discover a good way to store energy from the winds and tides. Perhaps someone will learn to capture the energy of sunlight in an efficient manner.

Not long ago scientists discovered how to get energy from atoms of uranium and plutonium. But so far this atomic energy has been used only for destruction. Someday we may learn to use it for the benefit of mankind.

*Self-Testing Exercises.* 1. Explain as well as you can how the energy of the sunlight gets (*a*) into the wind, (*b*) into water in mountain streams, (*c*) into coal, (*d*) into gasoline.

2. Do you think that there is likely to be a permanent shortage of fuel before you die? Give your reasons for your opinion.

3. Make a list of the possible energy supplies of the future. After each one, tell why it is not used now.

4. Why are inventors trying to capture the energy of sunlight directly?

*Problems to Solve.* 1. Trace the energy from the sunlight to an electric bulb, assuming that it passed through a water turbine.

2. Trace the energy from the sunlight to an electric motor, assuming that it passed through a steam turbine.

3. Trace the energy from the sunlight to the wheels of an automobile.

4. How have men tried to harness the energy of the sun? Look up "Solar Engines" in encyclopedias.

5. How have men tried to harness the tides? See what you can find on this topic in reference books.

## Looking Back at Unit 15

1. Energy from the sun reaches the earth and is used to do our work. List the important supplies of this energy on the earth that have been successfully harnessed. For example, one supply would be "The energy of fuels."

2. State in one sentence how the first supply of energy you name has been harnessed. Then do the same for each of the others.

3. List the energy transformations that occur when energy is harnessed in the ways described in exercise 2.

4. Show that you know the meaning of the following science words:

| | | |
|---|---|---|
| *kinetic energy* | *watt* | *overshot wheel* |
| *potential energy* | *rotor* | *kilowatt* |
| *undershot wheel* | *turbine* | *dead centre* |
| *carburetor* | *radiator* | *water-tube boiler* |
| *horse-power* | *eccentric* | *fire-tube boiler* |
| *Pelton wheel* | *piston* | *power stroke* |
| *cylinder* | *cycle* | *Diesel engine* |

## Additional Exercises

1. Read in reference books to find the answer to one of the following problems about steam engines.

*a*) How did a Newcomen engine use air-pressure?

*b*) What great improvements did Watt make in steam engines?

c) What were the main difficulties of the early inventors?

2. How can a steam engine use steam twice? Read about compound steam engines.

3. How is a *condenser* used with some steam engines? Read how James Watt invented the condenser.

4. Learn how a carburetor is constructed. Read all you can find in reference books, and examine real carburetors.

5. How are the parts of the electrical system arranged to produce sparks at just the right time in each cylinder of an automobile?

6. What are *super-chargers* on gasoline engines? Why are they used? How do they work?

7. How many power strokes occur during one revolution of a four-cylinder four-cycle gasoline engine? Of an eight-cylinder engine? Of a twelve-cylinder engine?

8. What disadvantages are there in having many cylinders in an automobile engine?

9. How does pressure change the boiling point of water? Learn,

if you can, how hot the water in a boiler gets when the steam pressure is 200 pounds per square inch.

10. What is *superheated* steam? How is it produced?

11. What is a *Corliss* engine?

12. Find out how *hydraulic rams* use water power to pump water.

13. Obtain a large sheet of paper. In the upper left corner draw a small "sun" with energy radiating from it. In the lower right corner draw a wheel and label it "Man's Work." Then complete your diagram by showing the different paths by which energy from the sun can reach the wheel and turn it. Give your diagram a title.

14. A rotating lawn sprinkler is a kind of water turbine. Explain why it turns when water flows through it.

## Books to Read

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We use electricity in so many different ways that a person wonders how the world ever got along without this silent, invisible kind of energy. Electricity cooks food, makes ice, lights homes, runs machines, sends music to our homes, helps deaf people to hear, aids in surgical operations, and shows the dentist where our teeth are decayed. In the picture on this page electricity is making ice, keeping foods cool, and, strange as it may seem, it is killing germs. The device that looks like an electric lamp is called a *Sterilamp*. It sends out rays that kill certain kinds of germs. Thus it helps keep food from decaying. (Photo by courtesy of Westinghouse)

# UNIT 16

# How Do We Obtain and Use Electrical Currents?

## Looking Ahead to Unit 16

In a fanciful story written centuries ago, Aladdin had only to rub his magic lamp to make a genie appear and carry out his wishes. Such stories have always been interesting, even though no one really believed they were possible. Yet, within the last hundred years the discoveries of scientists and inventors have put at our command a servant as powerful and mysterious as Aladdin's genie. In homes, factories, autos, and trains we need only to push a button to have almost unlimited energy obey our wishes. As you have already guessed, this servant is energy in the form of electric current.

The things electricity does for us make a long list. You have seen it at work in many ways. It floods our homes and streets with light during the night; it runs our machines, taking the place of much hard work and of clumsy steam engines; it keeps our food cool in one corner of the kitchen while it heats an iron in another corner; it sweeps the carpets and ventilates our rooms; it charges storage batteries, gives our metal-ware a covering of silver or chromium, and produces chlorine to purify our drinking water. It brings us the voices of our friends, from across the ocean if necessary; and more like a genie than ever, it catches mysterious messages from the air to fill our homes with music and to bring us the latest news.

People have not used electrical current very long. Less than 140 years ago Alessandro Volta, an Italian scientist, discovered the first practical way to make an electric current. Volta discovered how to change chemical energy into electrical energy. His invention was the ancestor of our modern electric cell. The electric cell was used at first by scientists to carry on experiments. Of course, it produced only a very small amount of electricity—

FIG. 365. Alessandro Volta explains his electric cell to Napoleon Bonaparte. Volta's cell was of greater importance to the world than all of Napoleon's military victories.

so small, indeed, that 2000 of these cells were needed for some of the experiments the scientists were doing. You can easily see that such a cell had to be greatly improved or some other way of making electricity had to be invented before we could use electricity as we do today. The practical use of electricity in our homes would never have developed far if it had not been for a great discovery by the British scientist Michael Faraday. About 110 years ago Faraday found a way to change the energy of a moving machine, such as a steam engine, into an electrical current.

Just to list all the things that electricity does may make it seem very mysterious to you. You may feel that it is much too strange and difficult for you to learn how electricity works in the many electrical devices that are all about you. However, as you study this unit, you will find that there are really only two important ways of producing electrical current. In the same way, when you study how electricity works for you, you discover that an electrical current can do only about four or five really different things. When you understand these few things, you can understand the uses of electricity reasonably well. What are the important effects of an electrical current that we use? How does it make a motor turn? How can it heat an iron and cool a refrigerator? What is a transformer? How can an induction coil make terrible shocks from a harmless dry cell? In this unit you will find answers to these questions and to many others.

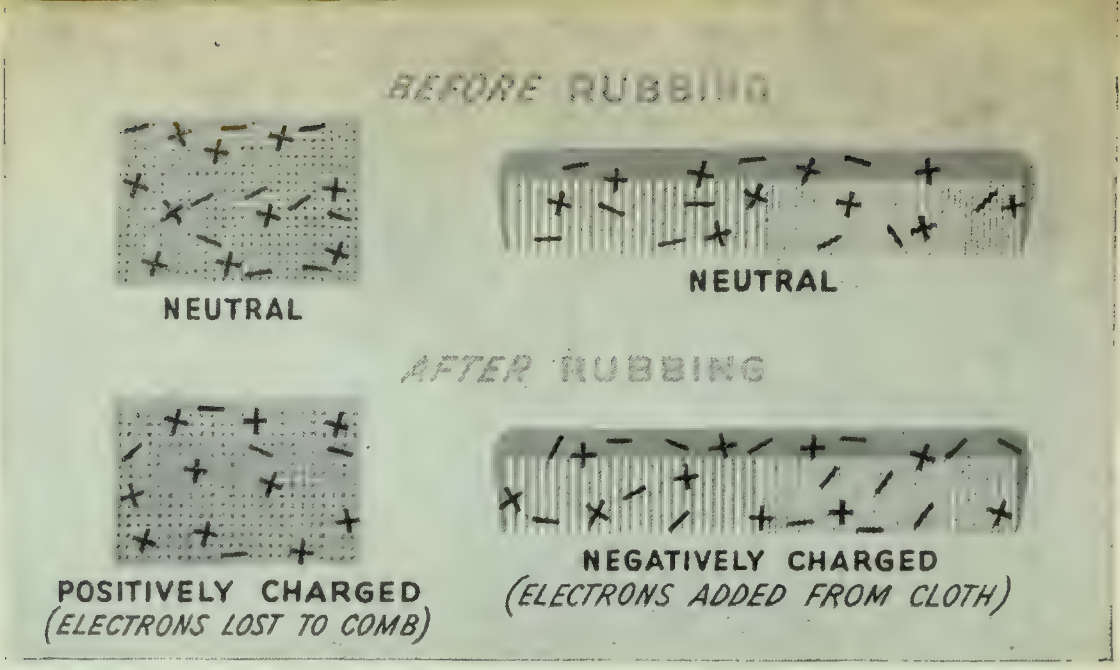



FIG. 366. This picture shows how a comb becomes electrically charged when you rub it with a piece of wool cloth.

## 1. What is electricity?

MANY PEOPLE WOULD BE GREATLY PUZZLED if you asked them to tell you just what electricity is. Have you wondered about it? A wire that is carrying electricity seems no different from any other wire. Yet, if you touch a wire that is carrying an electric charge, you may be severely shocked or killed. What is this strange force called electricity? Thousands of years before the time of Volta and Faraday, the ancient Greeks had noticed that amber would attract little pieces of straw and thread after it had been rubbed. (Amber is yellowish-brown gum, or tree sap, that has hardened into a stone-like material. It is used to make beads and other ornaments.) The Greek name for amber was "elektron"; so things that acted like amber were said to be *electric*. We now say that they have an *electric charge* or that they are *charged with electricity*.

For a long, long time scientists were just as badly puzzled about electricity as you may be. Then, within the last fifty years many of their experiments and discoveries began to fit together, and they came to have a rather clear idea of what this invisible force is. You remember that the molecules of all materials are made of atoms. Scientists have discovered that all atoms seem to be made of two kinds of electricity—*positive* electricity and *negative* electricity. Every atom of every substance contains both kinds. In every atom the positive and the negative charges just balance each other; so the atom is *neutral*, or uncharged.

Scientists have further discovered that the negative electricity exists in the form of tiny particles called *electrons*. These elec-

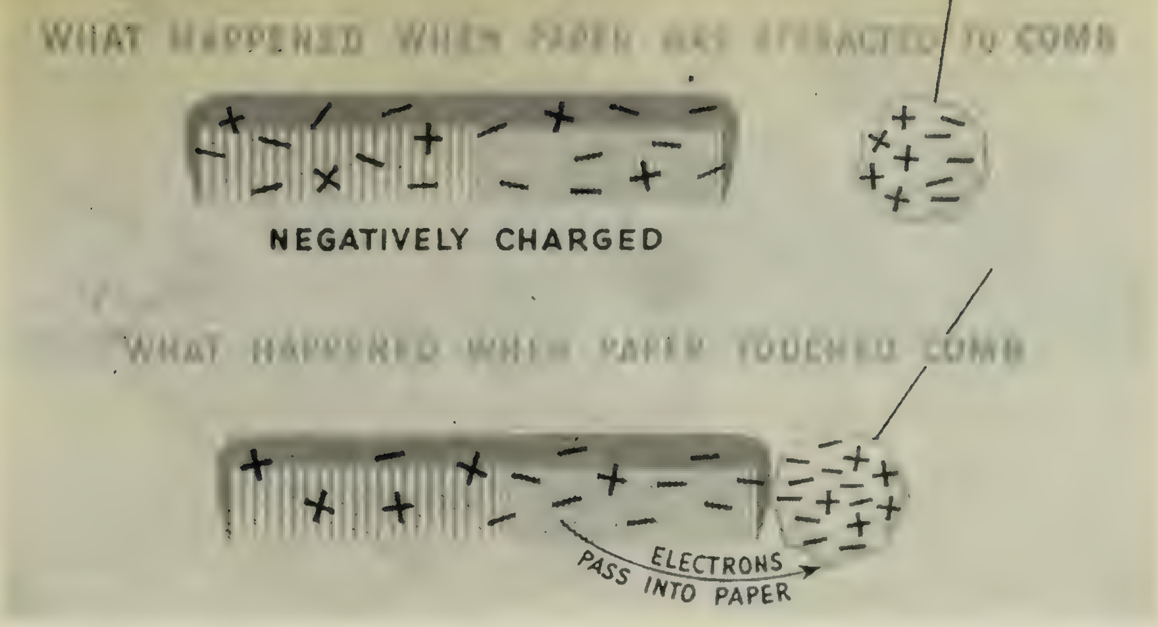



FIG. 367. Hang a dry paper wad or a ball of pith on a piece of silk thread about a foot long. Charge a comb by rubbing it with a piece of woollen cloth and bring it near the wad. What does the wad do at first? Then what does it do? Can you explain why it acts the way it does? Try the same experiment with a glass rod rubbed with a piece of silk cloth. What happens this time? Why?

trons are able to move about quite easily. They can leave one material and go to another or move easily through some materials. Every atom of a material also contains one or more particles that have a positive charge. The positive particles are called *protons*. Protons are nearly 2000 times as heavy as electrons. Unlike electrons, they cannot move easily. In all solid substances they seem to stay in their places. In every atom there is usually an equal number of electrons and protons; therefore the atom is neutral.

You can see that under ordinary circumstances any material is neutral because the numbers of positive and negative charges are just equal. But if some of the electrons are taken away from a neutral material, the material will become positively charged. And if we add electrons to a material, it will become negatively charged. Now let us suppose that we have one object which is positively charged and one which is negatively charged. If we bring these two objects together, what do you think will happen? Some of the electrons from the negatively charged body will move into the positively charged body. This movement of the electrons takes place because like charges of electricity repel each other, and unlike charges attract each other. In other words, the electrons in the negatively charged body will repel each other, that is, push each other away. The electrons will be attracted by the positive charges in the other body; therefore they will move over to it.

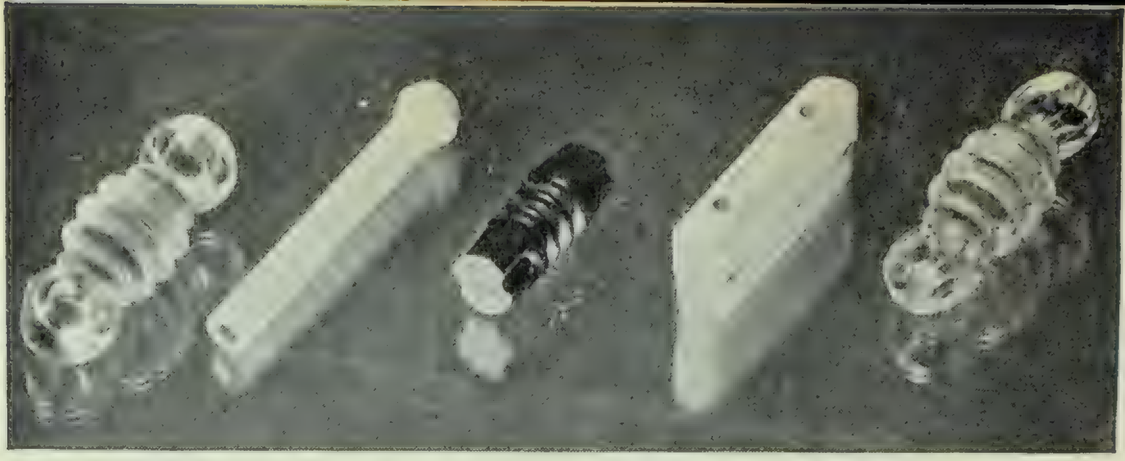


FIG. 368. Electrical insulators of porcelain and glass

In an electric cell (which you will learn more about in Problem 3) many extra electrons are forced into one of the *electrodes* of the cell so that it becomes negatively charged. (The electrodes of the cell are the parts to which the wires are connected.) Now, if the two electrodes are connected with a kind of material through which the electrons can pass, some of the electrons will be repelled, or pushed, through this material.

*Experiment 81.* WHAT MATERIALS WILL CONDUCT ELECTRICITY? With a dry cell and various kinds of materials find out which materials conduct electricity. Connect a dry cell with a bell. Cut one of the wires in the middle and scrape the ends bare. Touch these two ends to various kinds of materials. If the electrons can flow easily through a material, the bell will ring. Try copper, silver, brass, rubber, string, glass, and paper. Also try distilled water, tap water, and salt water.

These materials through which electric charges can pass easily are called electrical *conductors*. Silver and copper are our best conductors. Glass, rubber, porcelain, and dry air are *non-conductors*, or *insulators*. Because some materials are conductors and some are non-conductors, we are able to control the flow of electricity. When we want electrons to move, we use a good conductor to make a path for them. We provide a copper wire where we want the electrons to go. To make the electrons go where we want them to go, we let the wire touch only non-conductors and insulators.

You have already guessed what is going on in a wire that is carrying electricity; that is, you now know what scientists think an electric current is. It is a stream of electrons flowing through a conductor. To keep them flowing, something must keep putting electrons into one end of the conductor and taking them out at the other end, much as water is made to flow through a pipe. The water must be constantly pushing into one end of the pipe and running out the other end.

Now let us put together what you have learned about electricity: (1) There are two kinds of electricity, positive and negative. (2) Positive electricity seems to be made of protons that cannot move about easily. (3) Negative electricity seems to be made of electrons, which are much smaller and move about easily. (4) An object has a negative charge when it has more electrons than protons. (5) An object has a positive charge when it has fewer electrons than protons. (6) Like charges of electricity repel each other, while unlike charges attract each other. (7) Electrons can move easily through some substances, called conductors, but only slowly or not at all through other substances, called non-conductors, or insulators. (8) An electric current is a stream of electrons in a conductor.

*Self-Testing Exercises.* 1. If all materials contain positive and negative charges of electricity, why do they not always show an electrical charge?

2. What change must take place in a material to give it a negative charge? A positive charge?

3. Why will electrons move from a negatively charged body to a positively charged body?

4. What is a non-conductor, or insulator? Name several.

5. What is a conductor? Name several.

6. What is an electric current?

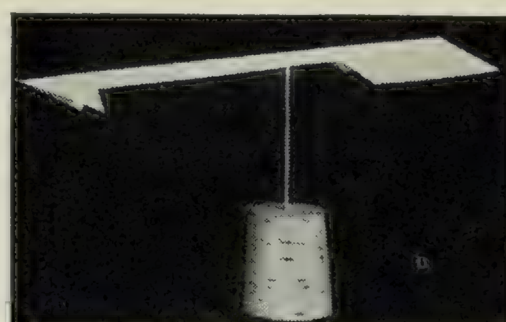


FIG. 369. Problem to Solve 3

*Problems to Solve.* 1. Tank trucks that carry gasoline always have a chain with one end attached to the metal frame of the truck and the other end touching the ground. Give a reason for this.

2. Why must people who work with gases that are easily ignited be especially careful about static electricity?

3. Cut a wide arrow out of writing-paper. Bend it into a V-shape, so that it will hang on the point of a needle stuck in a cork (Figure 369). Bring charged objects near the arrow and explain why it moves as it does.

4. Try Problem 3 with an arrow made of tin-foil.

5. When sheets of paper are run through a printing-press in winter, it soon becomes difficult to make a sheet lie on top of the pile. Why does this happen?

FIG. 370. Apparatus for Experiment 82

6. Cut two small balls out of cork or pith from a plant. Hang them up together by very fine silk threads. Charge both balls by touching them with a charged object. How do they behave toward the charged object? Toward each other? Why?

7. One brass screw on a dry cell is marked negative (—). The other is marked positive (+). When a wire is connected to both screws, which way will electrons move along the wire?

## 2. How do we control electrical current?

WHAT IS AN ELECTRICAL CIRCUIT? To use electrical current in ways that are helpful to us, we must make the current flow, guide it, and start and stop it whenever we want to do so. We do these things when we make an electric bell ring.

*Experiment 82.* HOW DO WE CONTROL ELECTRICAL CURRENT TO RING A BELL? Connect a dry cell to a push-button or switch and to a bell (or buzzer) with insulated copper wire so that the wire forms a path, or *circuit,* for the electrons to go from the cell through the bell and back to the cell again (Figure 370). You may put the push-button or switch either in the wire that goes from the cell to the bell or in the wire that carries the electrons back to the cell. Push the button or close the switch so that electrons can go all around the circuit. Does the bell ring? Explain the use of each part in controlling the electric current. What advantages has an electric bell over other kinds of bells?

The use of an electric current to ring the bell in this experiment shows you the important parts of any electrical *circuit.* The dry cell takes electrons from the centre, or positive, binding post and

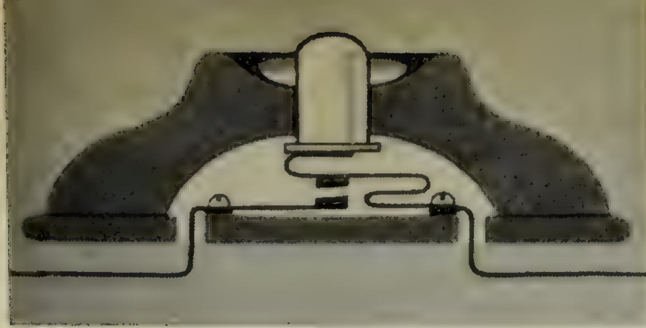


FIG. 371 (above). Diagram of a push-button. Do you see how the push-button is a *circuit breaker*, and also how it makes a circuit when it is pushed in?

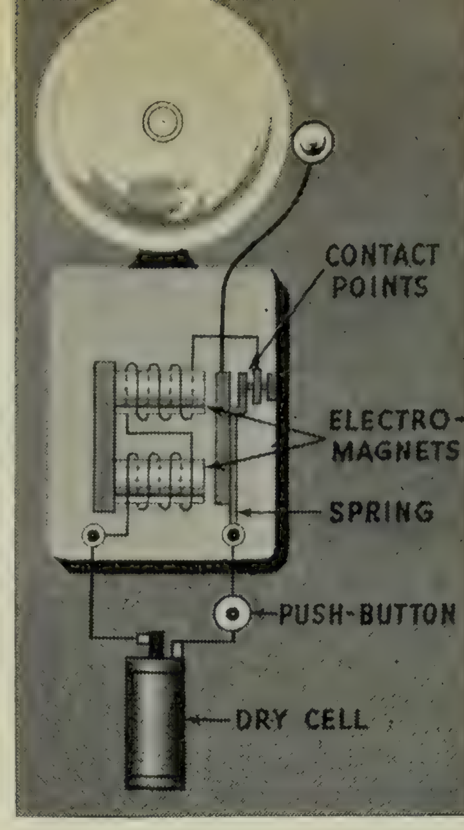



FIG. 372 (at right). The electromagnets have force only when a current is passing through the wire. Trace the flow of current from battery through bell and back to battery. At what point is the current broken when the clapper is pulled against the bell by the magnets?

pushes them out through the other, or negative, binding post. The copper wire is a good conductor; it allows the electrons to pass through it easily. Notice that there is one path to take the electrons to the bell and another to bring them back to the cell. This arrangement is necessary to form a complete circuit. Around the copper wire is cotton, silk, rubber, or enamel, so that the electrons cannot get out of the wire without going where we want them to. The bell uses the current of electrons to operate a magnet that pulls the clapper against the bell. This breaks the circuit at the contact point, the magnets loose their force, and the spring pulls the clapper away from the bell. The push-button, or switch, lets the electrons through when we want to ring the bell and makes a gap to stop the electrons when we do not want the bell to ring.

Every simple electrical circuit has these four parts: (1) something to make the electrons flow, (2) a good conductor arranged in a complete path for the electrons, (3) one or more devices to start, stop, or regulate the current, and (4) something to use the current. Let us see how electrical circuits in modern houses provide these four parts. The current is brought to each house by at least two wires that come from a machine called a *generator*. The generator makes the electrons flow by taking electrons out of one wire and forcing them into the other wire. The generator is in a "power-house," where it can be run by an engine or by a water-wheel. Where the wires come into the house there is a large switch to turn the current on or off in all the wires of

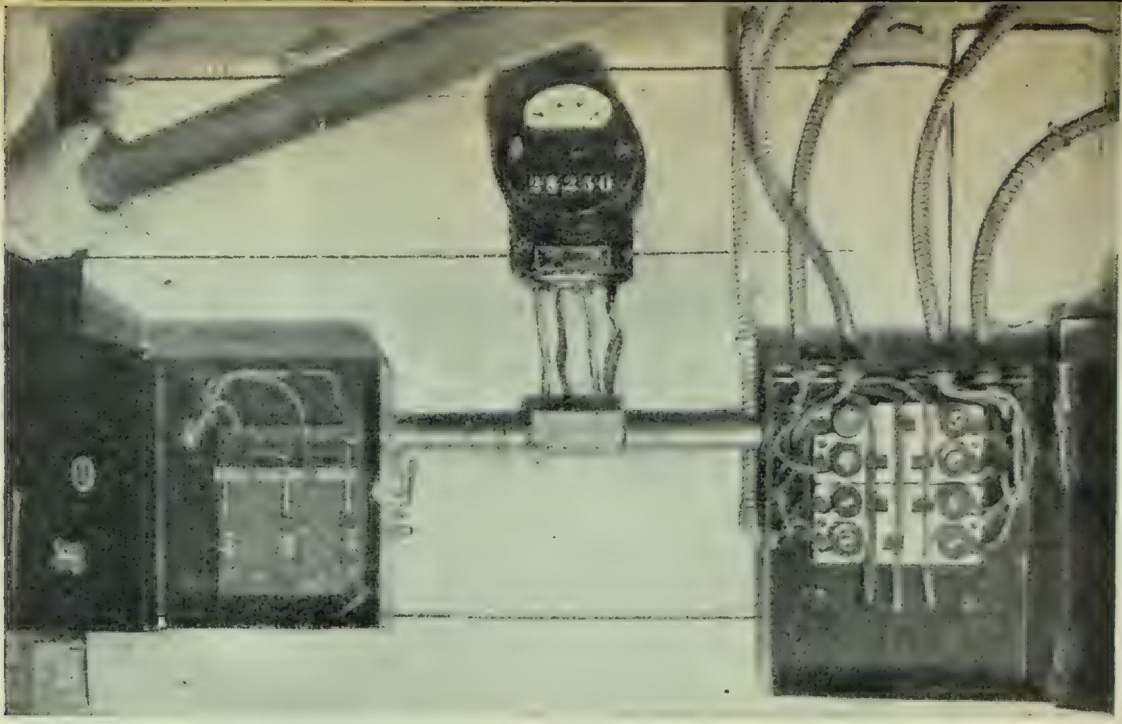


FIG. 373. At the left is the metal switch box. In the middle is the meter for measuring the amount of electricity used. At the right is the fuse box with eight fuses. Notice the armored cables that carry the wires from the fuse box throughout the house. Between the two boxes is a pipe through which the wires run.

the house. This switch is protected by a steel box, so that it will not be touched by accident. In the same box or in another one near by are *fuses*, which are automatic *circuit breakers*.

The fuse works the way it does because of an interesting characteristic of electrical currents. Every electrical current meets some *electrical friction*, or *resistance*, as it passes through its conductor. You know that when two objects are rubbed together, the mechanical friction produces heat. Electrical friction, or resistance, also produces heat. And the larger the current, the greater is the amount of heat. In fact, when we send twice as much current through the wire, the wire gives out four times as much heat. If the wires in a house carry only as much electric current as they should, they give out heat to their surroundings as fast as it is formed. They do not become hot. However, if we connect too many devices with the wires, so much current will flow that the wires will become very hot. They may even become red-hot. Then they will burn away the insulation, and they may even set the house on fire.

All the electrical current that goes through the wires in a house must also go through a fuse. Sometimes it goes through several fuses. Each fuse is a piece of soft metal. Usually it is inside a porcelain or glass "plug" that is easily screwed into the circuit. This soft metal fuse is made just the right size to carry a safe current without getting hot. But as soon as a dangerous

FIG. 374. Screw-plug fuses. The fuse at the right has been "burned out."

amount of current goes through it, the fuse metal gets hot, melts, and automatically stops the current. The fuse keeps the wires in the house from getting too hot, because it breaks the circuit if too much current is passing through the wires. When the metal in a fuse melts, a new fuse must be put in. Usually you will find one pair of large fuses for all the electricity used in the house, and several pairs of smaller fuses for the circuits in different parts of the house.

From the switch and fuses, wires run in pairs to all parts of the house where the current is used. The wires in all carefully wired houses are well insulated. They are covered first with cotton thread, then with rubber, and outside the rubber with cotton cloth. Even insulated wires are never allowed to touch wood or nails. In some houses they are fastened to porcelain insulators. Where they go through a wall, they are put inside porcelain tubes or other special tubes. However, the best way is to run the insulated wires inside metal pipes or in what is called "armored cable" (Figure 373) to metal boxes where lights, switches, or "outlets" are located. When wires are enclosed in metal pipes or cables, rats and mice cannot chew off the insulation.

HOW ARE CIRCUITS ARRANGED IN PARALLEL AND IN SERIES? The lights and other devices that use the current are all connected in such a way that part of the current of electrons can go through one light and right back to the generator. Another part goes through another light, and so on (Figure 376). This plan of connecting devices together is known as a *parallel circuit*, or parallel connection. When several devices are connected "in parallel," you can turn on one light or one toaster without having everything else going. However, each light or toaster or iron

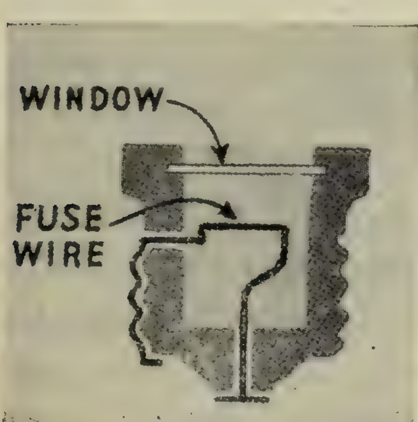



FIG. 375. A fuse

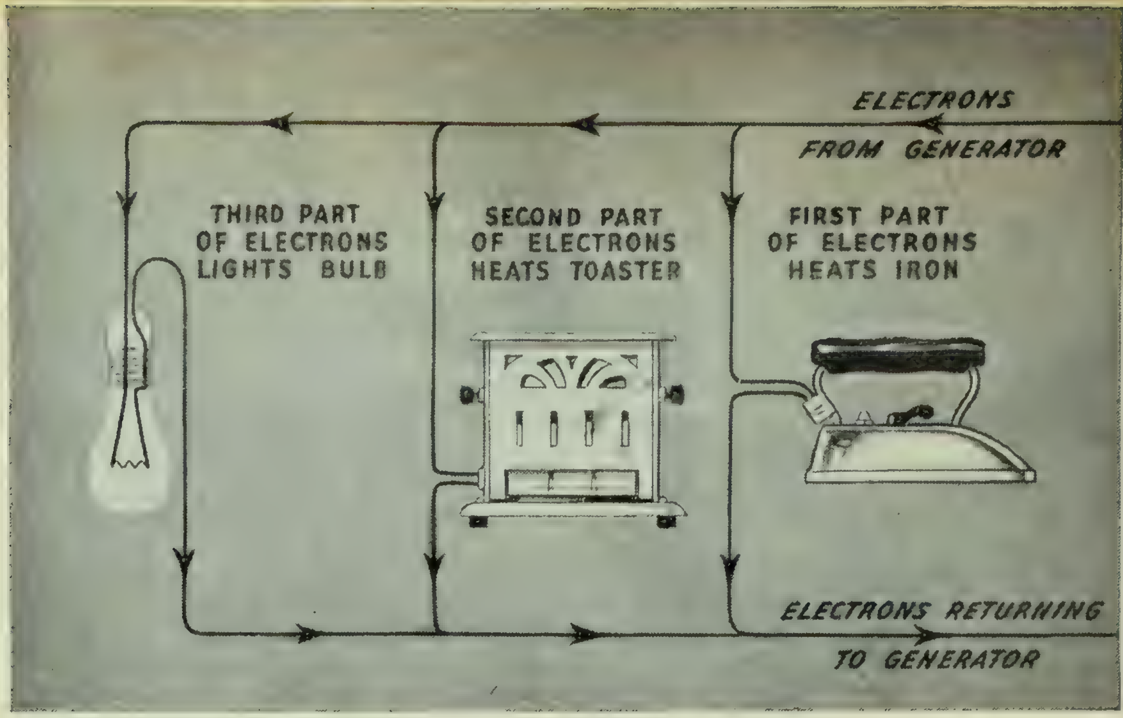



FIG. 376. How a number of electrical appliances can be connected in parallel so that electrons can flow through any one of them

that you turn on requires that much more current. If you turn on too many devices, enough current will go through the wires to melt the metal in the fuse. If this happens, you should turn off some of the devices before you put in a new fuse.

Sometimes two wires touch each other, or a boy sticks a piece of metal into a light socket. Then the electricity can go back to the generator without going through a lamp or a toaster or a sweeper. This is called a *short circuit*. Because the current does not have to flow through some electrical device, there is very little resistance to the flow of the electrons; so the amount of current that can pass through the wire is greatly increased. When this happens, so large an amount of electricity can get through that usually a fuse melts. You should be careful to find the trouble in the wiring before putting in another fuse. Why?

One of the two wires that go to an electrical device usually goes through a switch of some kind so that we can turn that device on and off without affecting other devices. Sometimes the switch is in the socket right above the light bulb. Sometimes it is in the wall near the door. Can you see how the wires would need to be connected to have the switch near the door?

Notice that a switch and a lamp are connected to each other so that the electrons go through one and then through the other when the switch is closed. This method of connecting devices together forms a series circuit; that is, the devices are connected *in series* (Figure 377). Each electron must go through every device in the series, or there is no current for any of them.

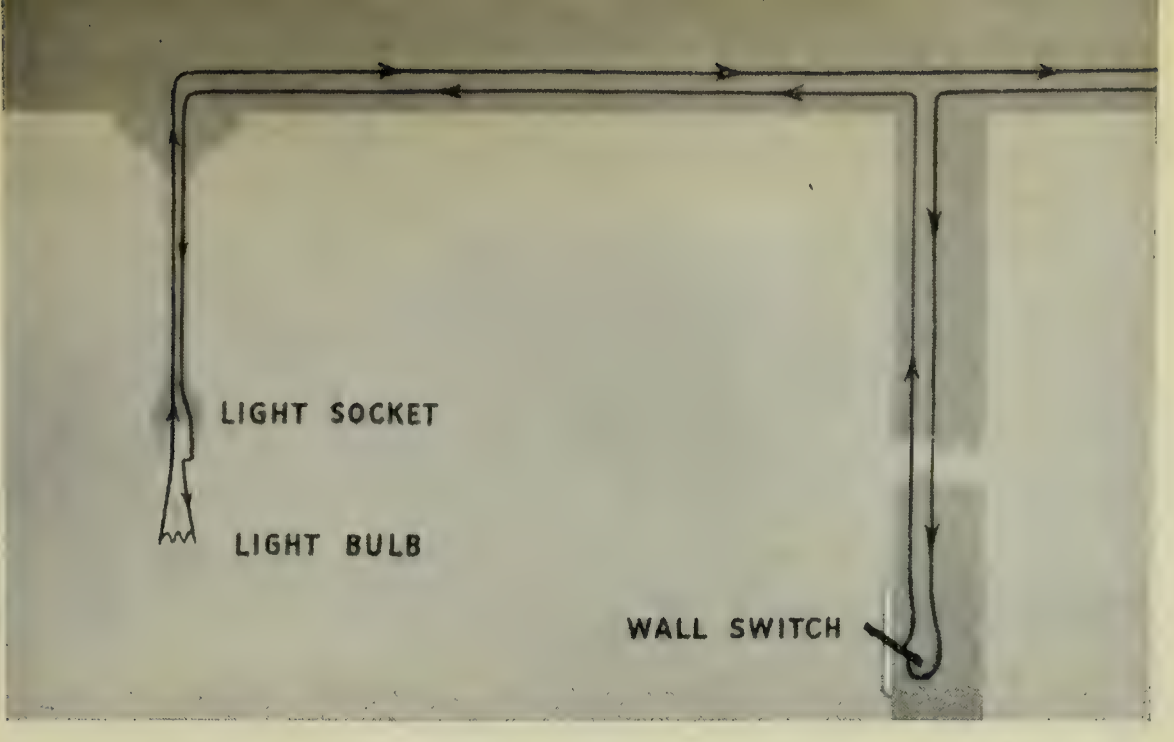



FIG. 377. How a light is connected in series with a switch. Does the drawing show the light on or off?

*Self-Testing Exercises.* 1. What are the important parts of a simple electric circuit? Diagram the correct connections.

2. Why do at least two wires go to each electrical device?

3. Why are fuses used in the electrical system of a house? Why do they sometimes "blow"?

4. Why are electric-light wires carefully insulated?

5. What is a short circuit? What usually happens in a house-lighting system when there is a short circuit?

6. (*a*) How are the wires arranged when several devices are connected "in parallel"? Use a diagram in your answer. (*b*) How are devices connected in series? Draw a diagram.

7. Make a diagram to show how the wires are arranged to turn a ceiling light on and off with a switch in the wall.

*Problems to Solve.* 1. Are the fuses in a house circuit in series or in parallel with the lights?

2. Draw a diagram to show how the wires, switches, and fuses would be connected to supply three different lighting circuits inside a house.

3. If you have electric wiring in your home, study the wires, switches, meter, and fuses to see how they are connected. Then make a diagram of as much of it as you can find out about.

4. Take a light socket to pieces and find out how the electricity gets to the lamp and how it is turned on and off.

5. If you had to put a new light socket in the place of a worn-out one, how would you protect yourself from a shock?

6. When a fuse blows, some people put a one-cent piece behind the used fuse to carry the current instead of getting a new fuse. Why is this dangerous?

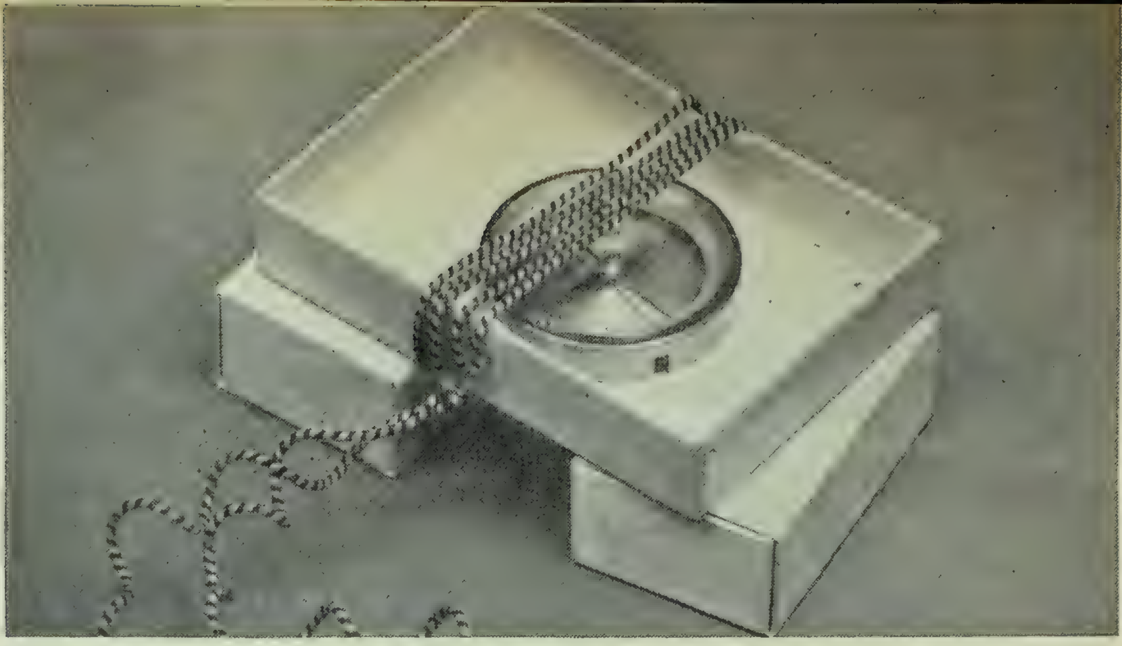


FIG. 378. A home-made galvanometer for Experiment 83

## 3. How do we make use of chemical change to produce electrical current?

HOW CAN YOU MAKE ELECTRICITY BY CHEMICAL ACTION? You now have a general picture of how electricity behaves and how we control it for our uses. You will next find out what really happens to make the electrons flow through the circuits. Scientists know several different ways of making electrical currents, but most of our current is produced by two kinds of devices. These two kinds of devices are *cells*, or *batteries*, and generators. In cells, chemical substances are arranged in just the right way to make the currents. Could you go to your own kitchen and make a cell that would really work?

*Experiment* 83. HOW CAN YOU MAKE A SIMPLE CELL? (*a*) For this experiment you will need some convenient way of telling when you have an electric current. Get a cardboard or wooden box just large enough to hold a magnetic compass (Figure 378). Wind some insulated copper wire of convenient size around the middle of the box about five times. Fasten the wire so that it will not unwind. Leave long ends to connect to your cell.

Place your compass in the coil and turn the box so that the compass needle and the coils point in the same direction. Support the box on its lid or on two books or boxes so that it is level and is not easily shaken. The device that you have just made is called a *galvanometer*. When a current of electricity passes through the wire, the compass needle will swing to the right or to the left, depending on which way the current is flowing through the wire.

*b*) Fill a glass tumbler or small jar about two-thirds full of dilute sulphuric acid. (To dilute the acid, pour one part of concentrated

FIG. 379. A home-made simple cell for Experiment 83

acid slowly into ten parts of water in a large beaker, stirring with a glass rod or tube as you do so. ***Caution:*** *Never pour water into concentrated sulphuric acid.*) With a hammer and small nail make a hole near one corner of a strip of zinc at least one inch wide and five inches long. Fasten the bare end of an insulated wire in the hole so that it makes good contact with the zinc. Prepare a strip of copper in the same way. The wider your piece of copper, the better the cell will work. Bend the strips to hang on the edge of the tumbler.

Connect the copper and zinc to your galvanometer so that any current they make will go through the coils around the compass. Hang the copper strip in the acid. Does anything happen to the strip or to the compass? Lower the zinc strip into the acid, but do not let it touch the copper. What happens to the compass? Notice the bubbles on the zinc and the copper. They are hydrogen.

Notice that the current gets weaker and weaker. This weakening of the current is caused by bubbles of hydrogen collecting on the copper plate. The hydrogen prevents the liquid from coming into contact with the plate and thus stops the flow of electrons. The cell can usually be made strong again by rinsing the copper plate in water and then wiping it off with a piece of paper towel. (Always rinse the plates before laying them down.) A cell of this kind with a rather large copper plate should give current enough at first to ring a small bell or buzzer. Try it.

c) Try two copper plates to see if they make a current. If you have strips of other metals, like iron, tin, aluminum, and lead, try them in the place of the copper and zinc.

d) Try a solution of vinegar, table salt, or ammonium chloride (sal ammoniac) instead of the sulphuric acid. Do other chemicals make a current? Try a sugar solution.

These experiments with metals and solutions give you the important ideas about making electric current by chemical action. You noticed that no current was produced if both plates were of

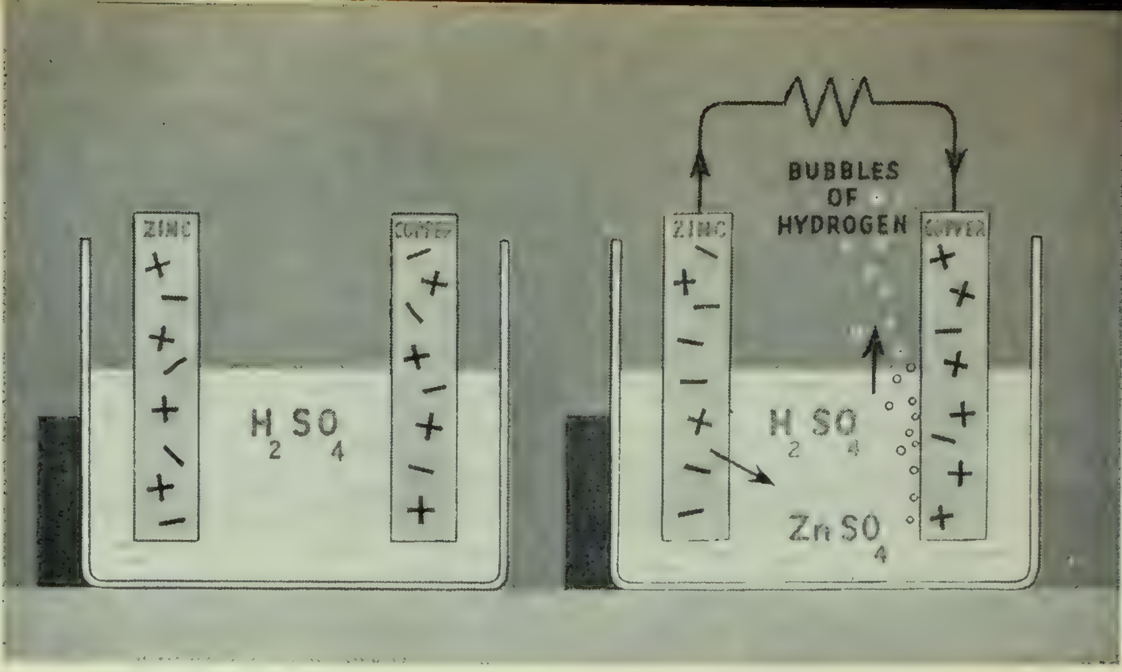



FIG. 380. The diagram at the left shows a cell at the instant the electrodes are put in the solution. From your study of this page and of page 535 you should be able to explain the right-hand diagram fully.

the same metal. Thus, for a cell that will make electric current, you need to have two plates, or electrodes, of different metals and a solution of some kind of chemical that will make a chemical change in one of the metals. Zinc and copper will make more current than most pairs of metals, as you have learned from doing Experiment 83.

In the cell you made, the sulphuric acid changed some of the zinc of the zinc electrode into zinc sulphate. The zinc sulphate dissolved in the liquid. When this happened, a great many electrons were left on the zinc plate. Since there were more electrons than protons, the zinc electrode had a negative charge. Experiments have shown that electrons repel each other. In the case of the cell, the electrons are repelled from the zinc plate through the wire to the copper plate. In this way a current of electrons flows from the zinc electrode through the wire to the copper electrode. At the copper electrode the electrons cause a change that produces hydrogen.

In every electric cell one of the plates is used up or changed chemically. In your cell the zinc plate is used up; it serves as fuel to make the cell work. Notice also that the chemical energy of the zinc and sulphuric acid is changed into the energy of the electric current. Your simple cell soon becomes useless because of the bubbles of hydrogen that cover the copper electrode. The bubbles of hydrogen gas act as insulation around the copper; therefore little current can get through. Let us see how a better kind of cell works.

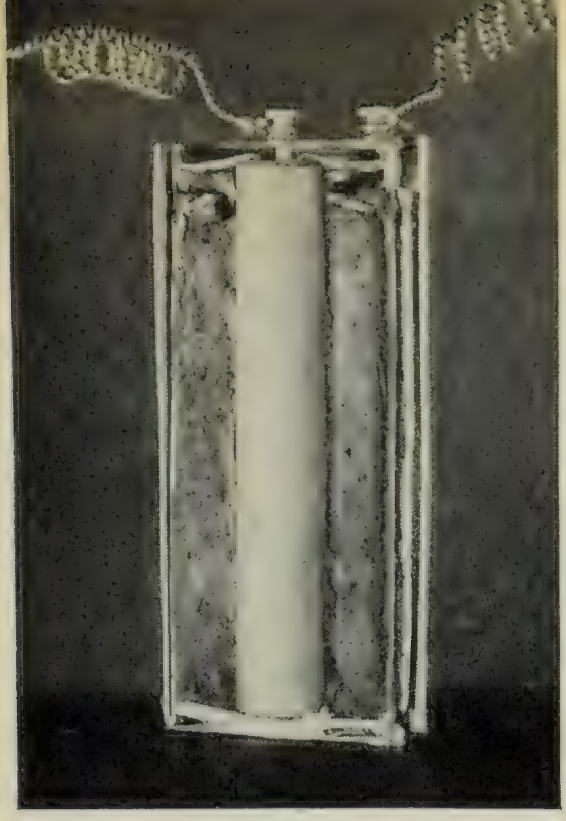


Fig. 381. A cut-open dry cell

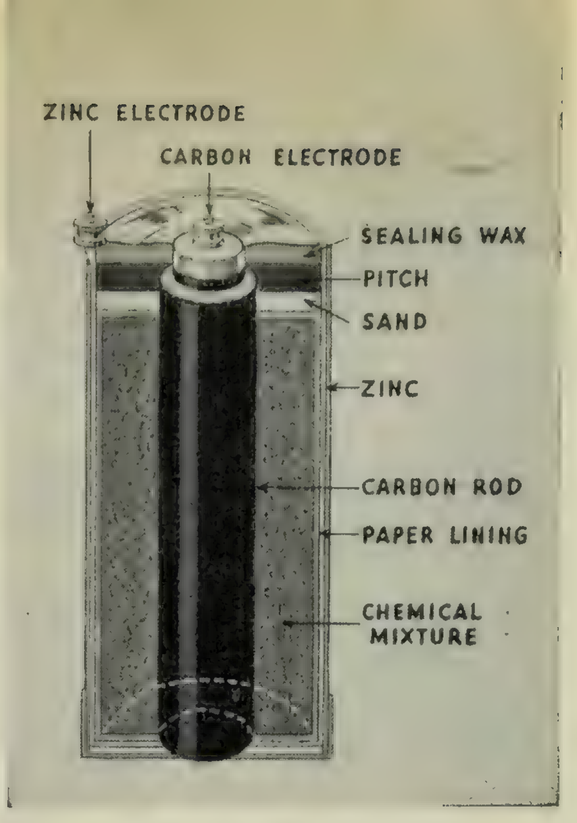



Fig. 382. Parts of a dry cell

How does a dry cell work? The battery in a flashlight is usually made of two or three small dry cells. To help find out how dry cells work, get a worn-out flashlight cell or a full-sized dry cell and see how it is made.

*Experiment 84.* how is a dry cell constructed? Remove the paper or cardboard covering from your worn-out dry cell. The metal can is made of zinc. Is it smooth and whole, or have the chemicals "eaten" holes in it? Lay the cell on a newspaper. With a hammer and dull chisel or screw-driver cut a slit down one side and around the bottom. Unroll the zinc and take the cell to pieces, layer by layer. Compare it with Figures 381 and 382. What takes the place of copper in this kind of cell?

The active chemical in a dry cell is ammonium chloride. (Did you smell ammonia in your cell?) The pasty mass in the middle contains water to dissolve the ammonium chloride. When the cell is delivering current, hydrogen collects on the carbon electrode in the same way that it did on the copper electrode of the simple cell. As you know, this will stop the chemical action, and the cell will grow weaker. To prevent the collection of hydrogen on the carbon, manganese dioxide is used. This chemical removes the hydrogen by combining with it to form water.

If a cell gives a large amount of current for a time, it becomes weaker because the manganese dioxide cannot combine with the hydrogen as fast as it is formed. After a rest the cell will again give a large current because the hydrogen has had time to combine with the manganese dioxide and to change into water. For

this reason it is better to turn a flashlight on and off occasionally rather than to keep it lighted for a long period of time. The action of the dry cell is very much like that of the simple cell. The ammonium chloride combines slowly with the zinc. As a result of the chemical action, electrons are left on the zinc electrode, and the zinc electrode becomes negatively charged. Part of the electrons are then repelled through the wire of the circuit.

As in the simple cell, the zinc acts as the fuel and is used up. As soon as holes appear in the zinc covering of a dry cell, the water evaporates, and the cell is "worn out." Boys sometimes collect used dry cells and renew them for experiments. They make nail holes in the sides of the cells and set each cell in a separate jar of water. The water soaks into the cell, and there are enough chemicals and zinc left to give current for some time.

*Self-Testing Exercises.* 1. What parts are needed to make a simple electric cell?

2. When a simple cell is made from zinc, copper, and sulphuric acid, does the zinc or the copper receive a negative charge?

3. What substances undergo a chemical change in a simple cell? In a dry cell?

4. Would you expect to get any electrical current from a simple cell made with an iron nail, a piece of an aluminum pan, and some sulphuric acid? Tell why.

5. (*a*) Make diagrams to show how four dry cells are connected in series. (*b*) What is the advantage of connecting cells in series?

*Problems to Solve.* 1. Is the positive connection of a dry cell in the middle of the top or at the edge? How do you know?

2. Why do flashlights occasionally need new batteries?

3. Is a dry cell really dry? Explain your answer.

4. Find out how cells are connected in parallel. For what purposes is the parallel connection used?

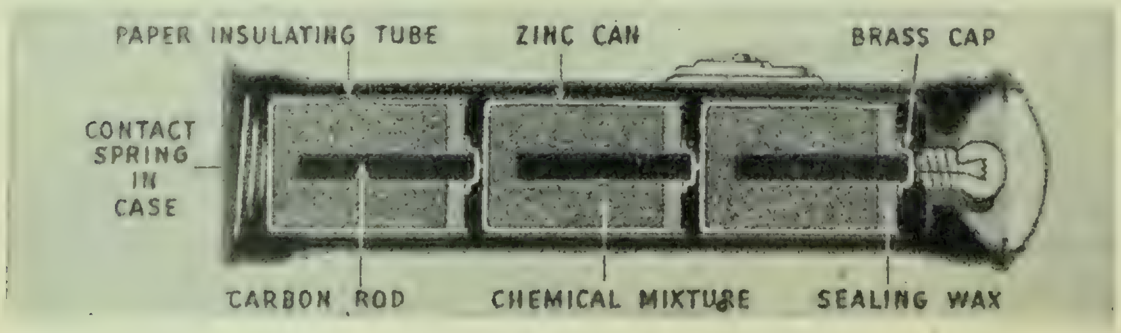



FIG. 383. Parts of a three-celled flashlight

FIG. 384. Apparatus for Experiment 85

HOW DOES A STORAGE BATTERY WORK? Every time you "step on" the starter button of an automobile, a storage battery is connected with a motor that cranks your engine. Ordinarily, the only attention a *storage battery* needs is to have distilled water added occasionally. Sometimes, however, the battery goes "dead." When this happens, it must be *charged;* that is, a current of electricity must be run through it. When this is done for a period of time, the battery will again supply a current. You can see that a storage battery differs from a dry cell. A dry cell cannot be recharged. When it is worn out, it must be thrown away. Now let us find out how a storage battery works.

*Experiment 85.* HOW CAN YOU MAKE A SIMPLE STORAGE CELL? (a) Fill a tumbler or small jar two-thirds full of a solution of sulphuric acid in water (one part of concentrated acid poured slowly into three parts of water). Place in this solution two clean lead plates that do not touch each other. Connect the lead plates to a bell. Does it ring? Why?

b) Connect three dry cells in series and send their current through the lead plates and sulphuric acid for several minutes. Watch carefully for any signs of chemical action. Disconnect the dry cells. Lift the lead plates out and examine them. (***Caution:*** *Do not get the acid on yourself or on the table.*) Are the plates now alike or different?

c) Return the plates to the acid and connect them to an electric bell. The bell should ring for some time.

d) When the bell has stopped, disconnect it and send current through the lead plates again. Then see how long the storage battery will ring the bell.

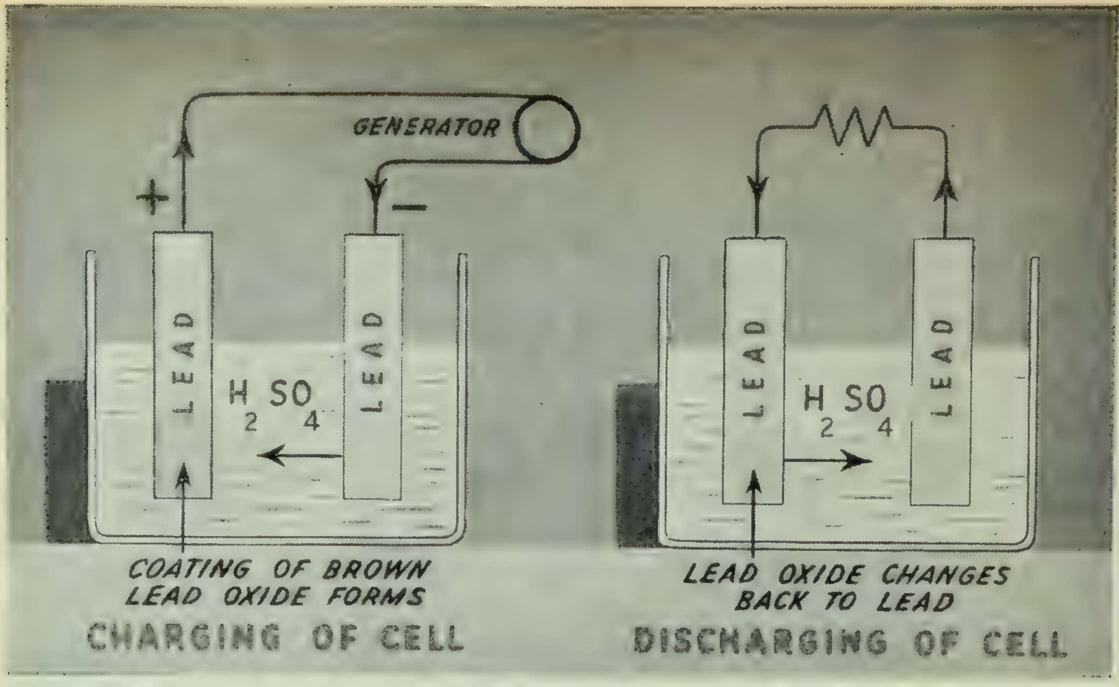



FIG. 385. After you have studied this page and page 541, explain this drawing fully to yourself.

Are you surprised to see how easily you can make a storage cell? However, you will be disappointed if you charge your cell and let it stand for a time. This simple cell will not remain charged very long.

The storage cell generates a current in the same way that your simple cell did. After the current had gone through your lead plates for a time, you noticed that one of them had a brownish covering. The other was a gray lead-color. The brownish material is an oxide of lead ($PbO_2$), formed because the electrical current produces oxygen at that plate. Thus there are really two kinds of plates in the acid—one of lead oxide and one of lead. When these are connected to your bell, the bell rings until the lead oxide has been used up or, in other words, until the two plates are alike again. To recharge the battery, it is only necessary to send a current through the plates in the opposite direction (Figure 385). When this is done, more lead oxide is formed, and the storage cell will again ring the bell.

Does the storage cell store electricity? If someone should ask you how to store some electricity, you would probably tell him to get a storage battery. But let us take a more careful look at what happens. The energy of the current that charges a battery causes a chemical change in the lead. This chemical change produces lead oxide on one of the plates. When this happens, the energy of the electrical current is changed to chemical energy. Thus, a storage cell does not store electricity; it stores a compound containing chemical energy. This chemical energy is changed back into the energy of an electric current when you

need it. But you cannot expect to get out as much energy as you put in. Ordinary storage batteries are from 65 to 75 per cent efficient; that is, they will give back only from 65 to 75 per cent of the energy used in charging them.

The storage cells we use in auto-lighting systems have in them the same materials you used in your simple storage cells. However, they are carefully constructed to give large currents for a long time. The plates are very large, and they are made in the form of lead frameworks, or *grids*. Into these grids spongy lead and lead oxide are pressed to make thick layers of active material. The plates are placed very close together in the cell with thin pieces of wood or rubber to keep them from touching each other. This kind of cell can be discharged and charged as many as 500 times before it wears out.

For most of our uses we need a stronger current of electricity than one cell gives us. Therefore, if you examine the storage battery of a car, you will find that it is really a battery instead of a cell, for it is made of three separate cells connected in series by lead bars across the top. Such a battery gives a current that is three times as strong as one cell would give.

A good storage battery that is well cared for lasts quite a long time. Some of the water gradually evaporates, and some is decomposed by the charging current. This water must be replaced regularly (about every two weeks) with water that contains no minerals. Distilled water is usually used, but clean rain-water caught in glass or earthen vessels may be used. Ordinary well water or faucet water should never be used. Water obtained from these sources contains minerals that will ruin the plates of the battery. In a fully charged battery the *hydrometer* reading for each cell of the battery shows from 1270 to 1300. (Pure water would read 1000 on the hydrometer.)

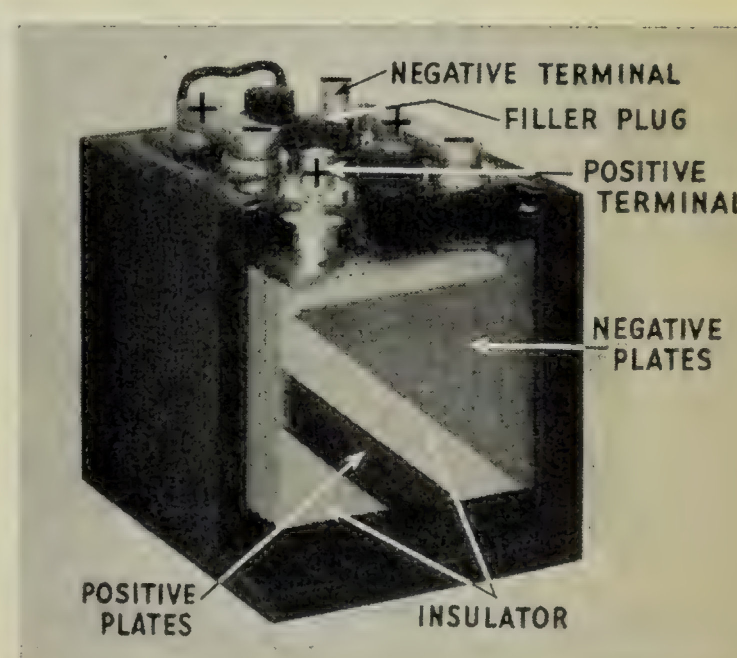



FIG. 386. A storage battery

*Self-Testing Exercises.* 1. How is a simple storage cell like any other simple electrical cell? How is it different?

2. What is the form of energy that is stored in a storage battery?

3. Why is it correct to call the part you put inside a large flashlight a battery instead of a cell?

4. Tell why a storage battery is a very useful part of an automobile. Why is it better than dry cells?

5. How can a person tell when the battery in his automobile is fully charged?

6. Why does a battery service-man put distilled water in a battery instead of tap water?

*Problems to Solve.* 1. Why do we often use batteries instead of generators; that is, what advantages do batteries have over generators as sources of electricity?

2. Why do dry cells have paper covers?

3. Is it correct to say that the zinc plate in a simple cell dissolves as the cell is used?

4. What advantages has a storage battery over a battery made of dry cells? What disadvantages?

5. Can you taste electricity? Attach a wire to each post of a dry cell or each plate of a simple cell. Clean the other ends of the wires and touch both to your tongue at the same time.

6. Can you make an electric cell from a lemon? Stick a sharp knife into a lemon in two places. Then push a strip of zinc into one place and a strip of copper into the other. Attach wires to the strips and test to see whether a current is being produced.

7. Visit a battery service-station and see what you can learn about the construction, charging, and repair of storage batteries.

8. Find out how an hydrometer works. That is, why does the little glass object inside float higher or lower in the liquid according to the condition of the battery?

## ¶ 4. How is electricity measured?

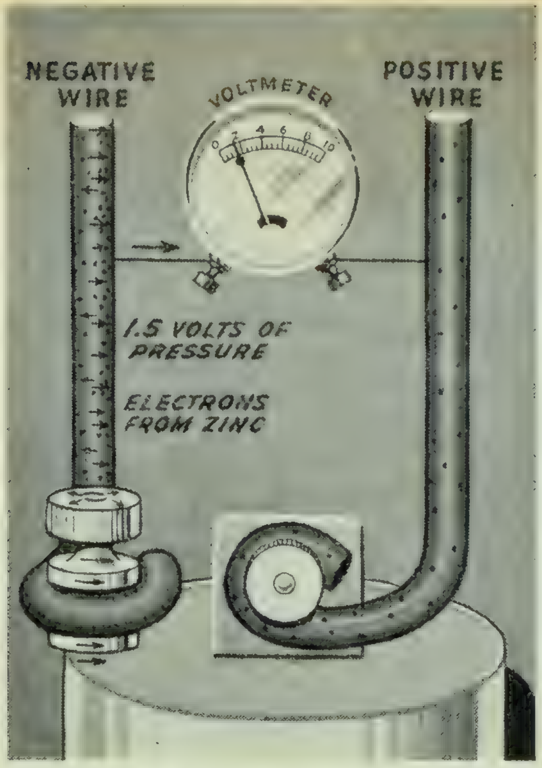
HOW IS ELECTRICAL PRESSURE MEASURED? When you talk about water pressure, you speak of the number of pounds per square inch; that is, you may say the water inside a pipe is pushing against each square inch of the pipe with a force of forty pounds. Now let us see how this helps us understand an electrical current. As the chemical change in the atoms of zinc causes

FIG. 387. Are these cells connected in series or in parallel? What voltage is being produced?

electrons to collect on the zinc plate, they build up a pressure, an *electrical pressure*. They do this because, as you know, the electrons have a negative charge and repel each other. Electrical pressure is measured in *volts* (named after the Italian scientist, Volta, who made the first cell). Thus, volts of electrical pressure are somewhat like pounds per square inch of water pressure. Scientists have an exact definition of a volt, but it will be better for you to remember that a dry cell gives about 1.5 volts of pressure. The simple cell you made in Experment 83 gave a pressure of a little more than one volt.

As you have learned, when we need more electrical pressure (or *voltage*) than one dry cell will give, we connect two or more cells together in a series to make a battery. Large dry cells, used to operate many small electrical devices, are usually connected as shown in Figure 387. Each cell adds 1.5 volts until we get the voltage we need. In a flashlight battery a piece of brass on top of the carbon rod is pushed against the bottom of the next zinc can (Figure 383). Thus they are really connected just like the cells in Figure 387. When cells are connected in series, all the electrons go through one cell after the other.

Where current is used for lighting homes, it is usually brought into the house wires with a pressure of 110 volts. That is, the pressure in the house wires is about as great as would be produced by 75 dry cells connected in series. The instruments that measure electrical pressure are called *voltmeters* ("volt-measurers"). To



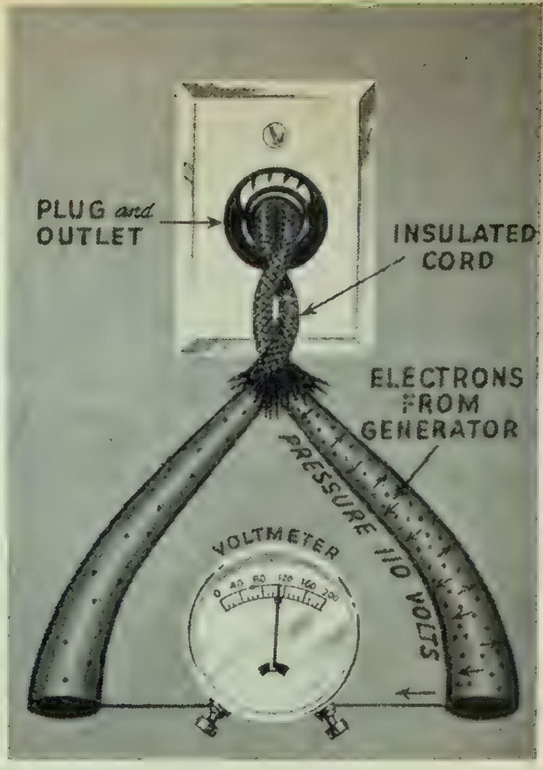




FIG. 388. A voltmeter is always connected between two wires that carry the current. What is the voltage in each circuit shown? If you can explain these drawings fully, you have a working knowledge of electrical pressure.

measure electricity a voltmeter is always connected to each of the two wires between which the pressure of the current is to be measured (Figure 388).

HOW DO WE MEASURE THE AMOUNT OF CURRENT THAT FLOWS THROUGH A CIRCUIT? In dealing with the flow of water we often need to know how much water is moving through a pipe or out of a faucet in a minute. In such cases we may say that the rate of flow from a pipe is five gallons a minute, or in pumping water for a city the rate of flow may be 60 million gallons a day. We measure the rate of flow of electricity, or the "size" of the current, in *amperes*.

Just as in the case of the volt, scientists have a very exact definition of an ampere of current. It is really a certain amount of electricity, a certain number of electrons, flowing through a wire in one second. But it will be better for you to remember that a 60-watt light-bulb when lighted at a pressure of 110 volts has about .54 amperes of current flowing through it. A large electric iron requires about five amperes of current to heat it. With electricity at a pressure of 110 volts, a one-horse-power motor uses about 6.8 amperes of current.

The number of amperes flowing through an electrical circuit is measured by an *ammeter* (short for ampere meter). Probably the most common use of an ammeter is on the dash of an automobile to show whether the battery is charging or discharging.

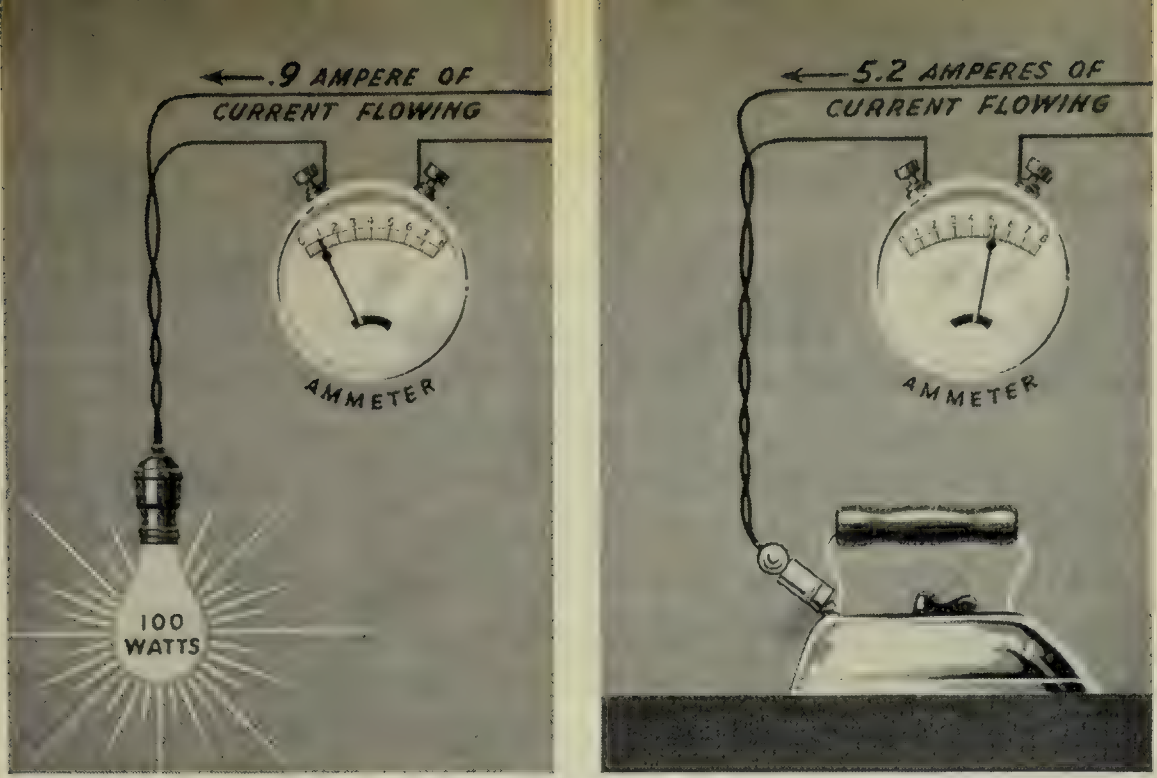



FIG. 389. An ammeter is connected into only one wire of the circuit. How many amperes are passing through each of these circuits?

An ammeter is really made very much like a voltmeter, but it is connected to the wires in a different way. All the current that goes through the electrical circuit goes through the ammeter; that is, the ammeter is connected in series with the device using the current (Figure 389).

*Self-Testing Exercises.* 1. Make a table like the one below and fill in the blanks to show a comparison of the flow of water and the flow of electricity.

| WATER | | ELECTRICITY | | |
|---|---|---|---|---|
| WHAT IS MEASURED | UNITS | WHAT IS MEASURED | UNITS | INSTRUMENTS |
| Pressure | Pounds per square inch | . . . . . . . . | . . . . . | . . . . . . . . . |
| Rate of flow | . . . . . . . | . . . . . . . . | . . . . . | . . . . . . . . . |

2. *a*) What is the usual electrical pressure in house wiring?

*b*) State the approximate number of amperes of electric current used by at least two devices.

*Problems to Solve.* 1. How do scientists define a volt? Look in an encyclopaedia or physics book to find the answer to this problem.

2. How do scientists define an ampere?

3. Approximately how many amperes of current would be required by seven ordinary 100-watt incandescent lamps?

4. A fuse in a house-lighting circuit will melt and break the circuit if more than 15 amperes of current flow through it. A boy in the house turns on one 100-watt bulb after another. How many will he have on when the fuse "blows" (melts)?

HOW CAN WE FIND THE NUMBER OF WATTS AN ELECTRICAL DEVICE USES? As you know, electric light-bulbs, irons, and toasters, as well as many other electrical devices, have on them certain numbers that tell where they can be used and how much energy they will use. In addition to the voltage of the wires to which they should be attached, lamps are labelled 25, 60, or 100 watts. An electric iron is marked 575 watts; a waffle iron, 800. The number of watts tells how fast an electrical device uses energy. This is known as the power of the electrical current that is being used. One horse-power is the same as 746 watts of power.

What connection do watts have with volts and amperes? When scientists chose the different electrical units—volts, amperes, and watts—they planned a very convenient relationship between them. The number of watts an electric iron uses is the number of volts of pressure multiplied by the amount of current that flows through it; that is, WATTS = VOLTS × AMPERES. If an iron uses 5 amperes of current at 110 volts of pressure, the electrical power it uses is 5 × 110, or 550 watts.

When you know this relationship, you can use it to solve another kind of problem. For example, you know that a large light-bulb is labelled 300 watts. How many amperes of current flow through it when it is lighted? Remember that *watts* = *volts* × *amperes*, or 300 = 110 × the number of amperes. If you divide 300 by 110, you will find the number of amperes of current used by the lamp (2.7 + amperes).

*Self-Testing Exercises.* 1. What is the difference between a 500-watt motor and a 1000-watt motor?

2. If you know the number of amperes and the voltage used by an electrical device, how can you find the amount of power required to operate it (in watts)?

3. If you know the voltage of an iron and the watts used by it, how do you find the number of amperes that flow through the iron?

*Problems to Solve.* 1. How many amperes does an 800-watt lamp use at 110 volts?

2. How many amperes are used by a 575-watt iron made to operate at 32 volts? At 110 volts?

3. How many 60-watt light-bulbs can be lighted with the current needed for an electric iron?

HOW DO WE MEASURE THE ELECTRICAL ENERGY WE BUY? Near the place where the electric wires enter a building, you can usually find an electrical instrument. If you ask someone about this instrument, he will tell you that it is an electric meter. This meter tells how much electrical energy has been used during the month. However, you now know that there are at least two kinds of electric meters. One kind measures volts; the other, amperes. This meter must be a still different kind, for it measures the total amount of electrical energy that you use. Its face is also different from the face of a voltmeter or an ammeter. Instead of a single pointer that swings back and forth to show the amount or pressure of the electricity, there are several little dials, with hands like clock hands that turn very slowly (Figure 390).

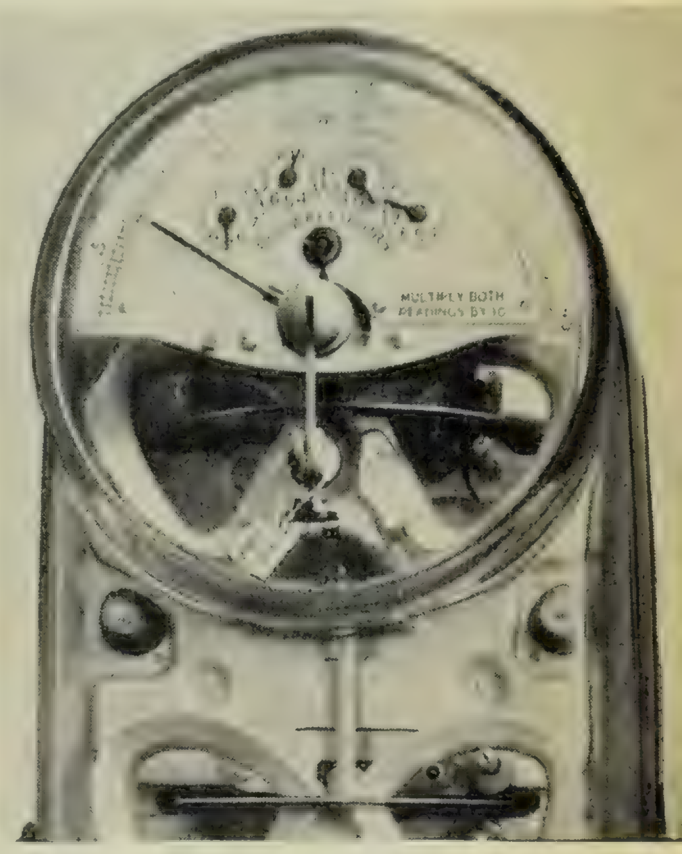


FIG. 390. An electric meter. The long pointer indicates the greatest amount of current used at any one time during the month.

Under the dials you will probably find the words *Kilowatt-Hours.* And on the meter you can usually find the label *watt-hour meter.* Scientists have agreed that the unit of electrical energy shall be the *watt-hour.* A watt-hour, as you can easily see, is the amount of energy that would be used by a one-watt lamp burning for one hour. How many watt-hours of energy would a 60-watt lamp use in an hour? Of course, it would use 60 watt-hours. In 24 hours it would use $24 \times 60$, or 1440 watt-hours.

You can see that a watt-hour is a rather small amount of energy. Even a small family would use a great many watt-hours in a month. Therefore scientists and engineers have decided to use a more convenient unit, known as the *kilowatt-hour.* One kilowatt-hour of energy is equal to 1000 watt-hours. The dials on electric meters tell how many kilowatt-hours of electric energy have passed through them. If there is a meter in your house, you will

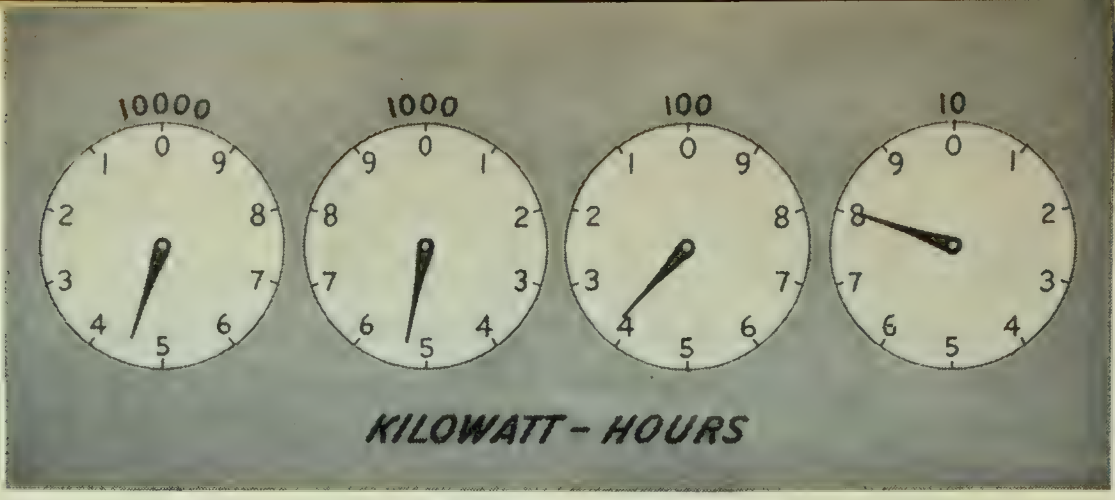



FIG. 391. The reading on these dials is 4538.


FIG. 392. The same dials as above, but a month later. What is the reading? How much electricity was used during the month?

want to know how to read it. If you can read it, you can tell whether your bills for electricity are correct.

Figure 391 shows the dials of a watt-hour meter. The pointer on the dial at the right makes one complete revolution while ten kilowatt-hours of energy are being used. The dial second from the right makes one revolution for each 100; the third, one revolution for each 1000; and the fourth, one revolution for each 10,000. Therefore the reading is made by looking at the last figure passed by each pointer and by writing them down in the same order as the dials. Now answer the questions under Figure 392.

*Self-Testing Exercises.* 1. What is a watt-hour? A kilowatt-hour?

2. An electric iron was used for three hours. The iron required 450 watts to operate it. How many watt-hours of energy did the iron use? How many kilowatt-hours?

3. How many watt-hours of energy would an 800-watt waffle iron use in one-half hour?

*Problems to Solve.* 1. If a kilowatt-hour of electrical energy costs 5 cents, how much does it cost to operate a 60-watt lamp for 24 hours?

2. At the same rate how much was the cost of the ironing described in Self-Testing Exercise 2?

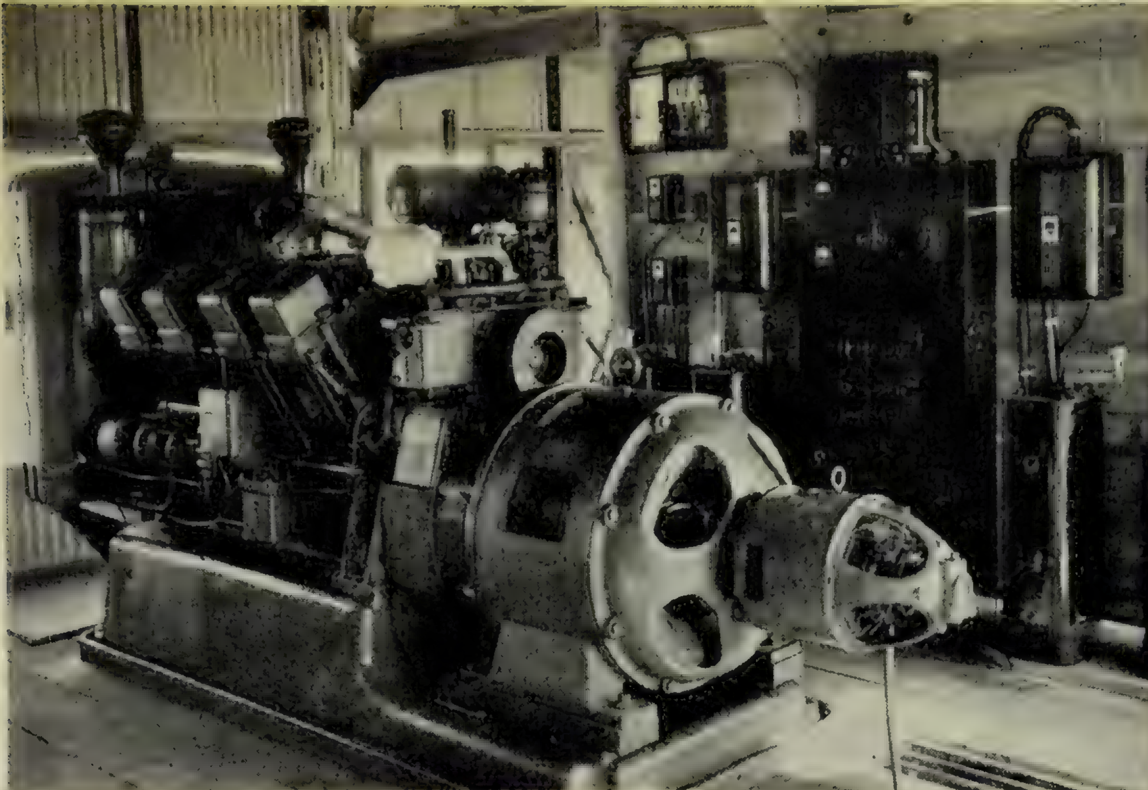


FIG. 393. This Diesel engine and electrical generator furnish the electricity to operate a dredge in a gold mine in Idaho. The engine really runs two generators (they are the two objects with a ring on top), but the smaller generator only supplies the electricity that is needed for the magnets of the larger generator.

3. What is the rate charged for electrical energy in your community? Usually the rates are given on the electric bills, or you can find out what they are by asking at the office of the company that supplies the electricity.

4. At the rates charged in your community, what should be the amount of the bill when two monthly readings were those shown in Figures 391 and 392?

## ¶ 5. How do we use mechanical energy to produce electrical current?

HOW CAN A MAGNET BE USED TO MAKE ELECTRONS FLOW? Cells and batteries are very convenient sources of electric current, and we use them a great deal. But if we had to depend on batteries for electric current, we could not afford to use electric lights, electric refrigerators, or vacuum-sweepers. The metal and chemicals that would be used up in the cells would be too expensive. We could have no large electric motors, no electric cars, no locomotives. More than 99 per cent of all the current we use in this country is made by generators, or *dynamos*. How can such a generator make electrical current? As you have already learned, it was the great scientist Michael Faraday who discovered that he could use magnetism to make an electrical current. Every electrical generator uses the principle discovered by Faraday about

FIG. 394. Experiment 86*a*. What kind of magnet do we call this U-magnet?

FIG. 395. Experiment 86*d*. How is this magnet like the magnets in the bell on page 529?

110 years ago. In order to understand how a dynamo generates an electric current, you must first get some facts about the force exerted by magnets.

*Experiment* 86. WHAT IS THE NATURE OF THE FORCE EXERTED BY MAGNETS? (*a*) Place either a bar magnet or a horseshoe magnet in a pile of iron filings and then pick it up. Do you find the same amount of filings clinging to all parts of the magnet? The points where the magnetism appears to be concentrated are called *poles*.

*b*) Get a thin piece of cardboard or a glass plate and some fine iron filings. Place the cardboard or glass plate over a horseshoe magnet. Sprinkle some iron filings on the glass plate, gently tapping the plate as you do so. Draw the arrangement of the filings.

*c*) Place a compass between the poles of the magnet. Does the compass needle point to the north pole or to the south pole of the magnet? The lines of force are always said to go from the north pole to the south pole.

*d*) Wrap ten turns of insulated wire around a large iron nail. Connect one end of the wire to a cell as shown in Figure 395. Bring the end of the nail near several smaller nails and touch the other end of the wire to the cell. Note that the small nails are drawn over to the large nail. How many nails will it hold up? Disconnect one wire from the cell. What effect does this have upon the magnet? Test the magnet with a compass. Does it have a north and a south pole? Reverse the direction of the current. What effect does this have upon the poles?

From the experiment you see that there are two kinds of magnets. The bar and the horseshoe magnets, made of steel, retain their magnetism and are therefore called *permanent* magnets.

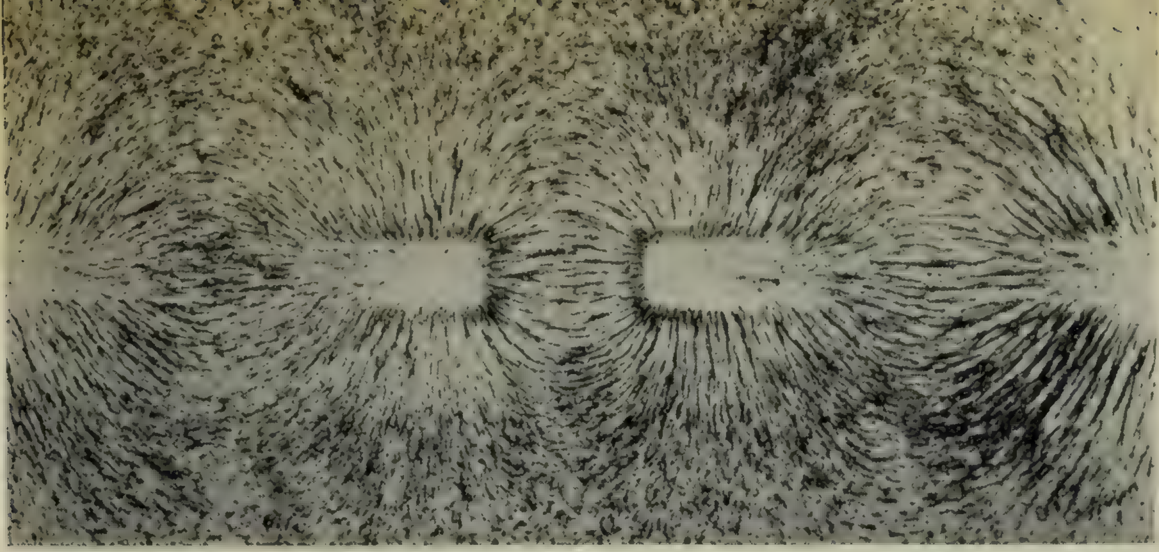


FIG. 396. In experiments with magnets you have probably shown the field of force with iron filings on cardboard or a glass plate.

When a current of electricity is sent through a coil of wire wound around an iron nail, you have an *electromagnet.* This retains its magnetism only so long as the current is passing through it. It is a *temporary* magnet. The experiment also shows that invisible lines extend between the poles of a magnet and affect pieces of iron placed in their paths. These are *magnetic lines of force.* All the lines of force taken together make up what is called the *magnetic field.*

Now let us see how magnets can be used to make electricity. There are many ways of showing how magnetism makes electric currents. An easy way is to use a magnet, a small coil of wire, and a sensitive galvanometer.

*Experiment 87.* HOW CAN YOU MAKE ELECTRIC CURRENT WITH A MAGNET AND COIL? (*a*) If you do not have a sensitive galvanometer, you will need to borrow one. You can make the coil yourself, as follows: Trim the end of a board until it is about three-fourths of an inch thick and one and one-half inches wide. Round off the corners. It is better to have the board taper a little toward the end you use so that the coil will slip off easily. Wind at least 100 turns of No. 30 or 40 insulated copper wire in a compact coil about the end of your board. Leave the ends of the wire long. Slip the coil off the wood and tie thread around it in several places to hold the wire together.

*b*) Connect your coil carefully to the galvanometer. Hold the coil still and move one end of a magnet through the centre of the coil. Is there a current? Remove the magnet, still watching the galvanometer. What happens?

*c*) Hold the magnet still and move the coil over one of its poles. Does this make a current?

*d*) Move the magnet or the coil more rapidly. Does the rate of motion make any difference?

FIG. 397. Apparatus for Experiment 87

c) Now use two magnets, with like poles of the magnets together. How does the strength of the current compare with that obtained with one magnet?

What you found out in Experiment 87 is exactly what Michael Faraday discovered about 110 years ago. You discovered that electrons try to flow in a wire whenever the wire moves across the invisible lines of any magnetic field. It does not make any difference whether the wire moves or the magnet moves. The electrons will flow just the same. In your experiment you moved a magnet through the centre of your coil. Each of the magnetic lines around the pole of the magnet cut across 100 wires. Enough electrons flowed around your coil and through the galvanometer to make the needle move. You were using the principle discovered by Michael Faraday: *Whenever a conductor (wire) cuts magnetic lines of force, electrons tend to move along the conductor.* If there is a complete circuit, there will be an electrical current. The more lines of force that are cut in a second of time, the more current will flow.

You can easily see three ways to have more lines of force cut in one second. You used two of them in Experiment 87. In one part of the experiment you moved your magnet more rapidly. In another you made a stronger magnetic field by using two magnets. The third way to cut more lines of force is to have more turns of wire in your coil. You will soon see that all three ways are used to get strong currents in generators.

FIG. 398. Apparatus for Experiment 88

HOW DOES AN ELECTRIC GENERATOR WORK? If you wish to do so, you can make a toy generator. Actually making such a device will help you understand better how a generator works to produce an electric current.

*Experiment 88.* HOW CAN A COIL OF WIRE ACT LIKE AN ELECTRIC GENERATOR? Get a straight piece of stiff wire at least six inches long. A steel knitting needle is excellent. Carefully push the wire through the ends of the coil you used in Experiment 87 so that you can spin the coil by rolling the wire shaft between your fingers. Connect the coil to the galvanometer. Hold it between the poles of a large U-magnet (Figure 398) or between the N-pole of one bar magnet and the S-pole of another. Rotate the coil rather rapidly and watch the effect on the galvanometer needle. Does the current go in the same direction all the time? What difficulty would you have in keeping your generator going all the time?

You have made your coil and magnet into an electric generator. The *magneto* shown in Figure 399 is a kind of generator that uses several magnets and a coil with many more turns of wire than yours. The wire of the coil is wrapped around a piece of iron that rotates very rapidly between the poles of the magnets. The iron helps make more lines of magnetic force right where the wires can pass through them. This is true because the lines of magnetic force can pass through iron more easily than they can pass through air.

FIG. 399. A magneto

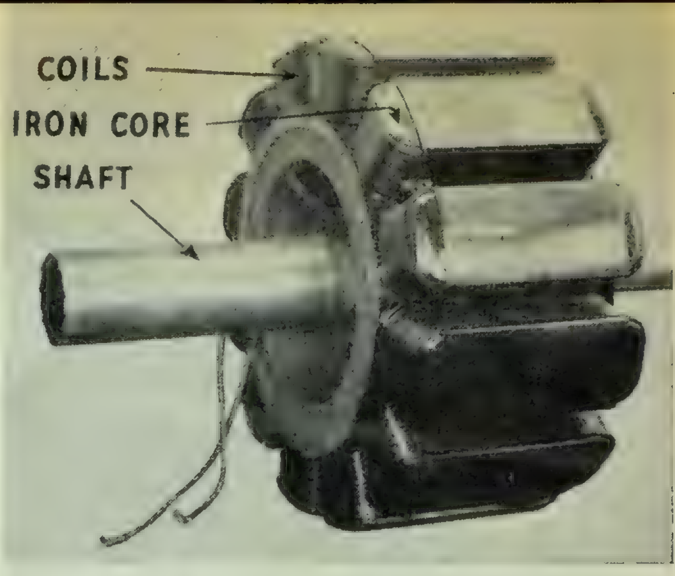



FIG. 400. Armature of a generator

The rotating piece of iron with its many wires is called the *armature* (Figure 400). This magneto makes current enough to light the lamp that you see connected to it. It will even give you a slight shock. Magnetos are used to ring the bells of many telephones in rural districts. Often they are used to supply the current for the spark-plugs of motor trucks and tractors. When large amounts of current are to be generated, permanent magnets are not large enough or strong enough. Then electromagnets are used in the generators and are called *field magnets* (Figure 402).

You noticed that the current from your generator was an *alternating*, or "back-and-forth," current. Most generators produce an alternating current, but it is possible to change this alternating current to a current that flows in only one direction. This is done by means of a device called a *commutator*, together with metal or carbon *brushes* (Figures 401 and 402). Such a current is produced by a *direct-current* generator (Figures 401 and 402). These generators are used to charge storage batteries and to furnish electricity for *electroplating*, that is, for putting a thin coat of one kind of metal on an object made of some other metal.

Electric generators are used in many different situations. Every recent aeroplane, tractor, truck, bus, automobile, and motor-boat carries an electric generator, and sometimes two or three. Every recent steam locomotive and every passenger car has a generator to make current for its lights. Those on the locomotives are run by small steam turbines, and those on the cars are run by belts from the axles. Many country homes have generators to make current for lights. Each large telephone exchange and radio station has several generators. Many pumping stations and factories make their own electrical current. Every large steamboat, ocean liner, and battle-ship has generators running day and night

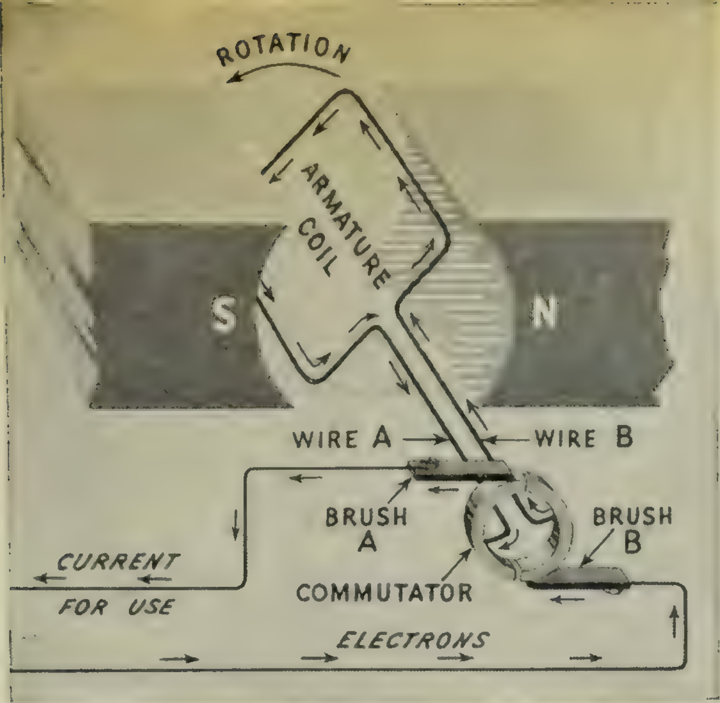



FIG. 401. Diagram of a direct-current generator. The *brushes* are made of carbon. The *commutator* is the device that makes the current flow in one direction through the wire.

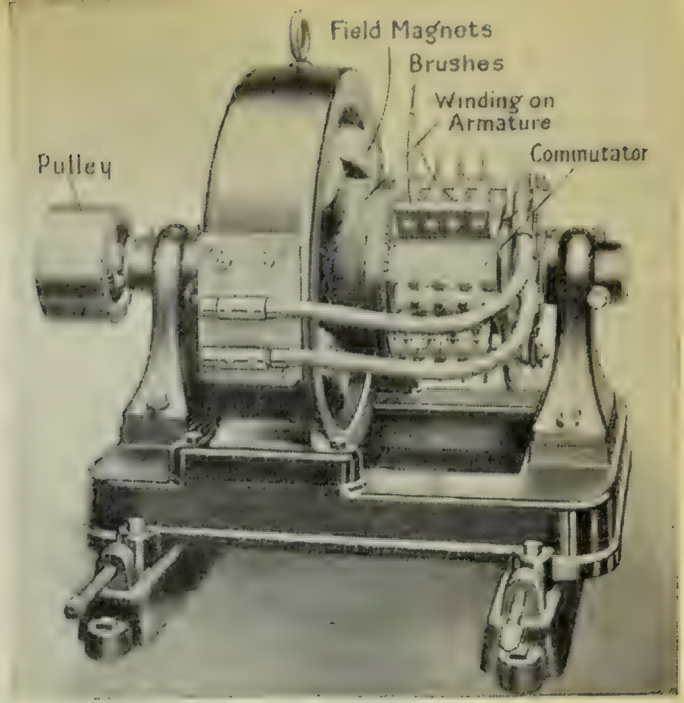



FIG. 402. A direct-current dynamo. Alternating-current dynamos are similar, but have no commutators.

to furnish current for electrical devices all over the ship. You can now begin to realize why the electric generator is one of the most helpful inventions ever made. And all these different machines that use generators, as well as hundreds of others, have developed from a slight jerk of a needle that Michael Faraday saw in the year 1831!

*Self-Testing Exercises.* 1. A magnet is near a coil of wire. The ends of the wire are connected to a galvanometer. Suddenly the needle moves a little. What has happened to the wires in the coil?

2. Draw a simple diagram to show how a magneto can make a current flow.

3. Name three ways of strengthening the current caused by a magnetic field.

4. Tell how you could make a toy electric generator.

5. What kind of current does a single coil give when it is rotating in a magnetic field?

6. Tell in one sentence what a generator does to energy.

7. List six different kinds of places where generators are useful.

*Problems to Solve.* 1. Tell where you have seen electric generators and what their current was used for.

2. How does a large electric generator use the three ways of getting a strong current from a magnetic field?

3. Learn how the commutator in Figure 401 changes alternating current into direct current. You may need to study reference books to help you.

4. Would it be a good plan to make a generator entirely of copper? Why?

5. If a generator produces only 80 volts when 110 volts are needed, what are some ways of raising the voltage?

6. Does a generator turn harder when it is generating a small current or a large one or when it is not generating? Explain why.

7. Why can generators with electromagnets be made to produce larger currents than those with permanent magnets?

## ¶ 6. How do we get heat energy and light energy from electrical current?

HOW DO ELECTRICAL HEATING DEVICES WORK? Of all the things operated by electricity, we are most familiar with those that produce heat. From some electrical devices we want light, but to get light we also make heat. Ordinary electric light-bulbs, irons, toasters, stoves, heating pads, arc lights, and electric furnaces all produce heat. They help us because they change electrical energy into heat. As you probably know already, every common heating device contains some kind of wire that becomes red-hot when the current is turned on. Why do these wires get red-hot, while the wires in the connecting cords do not?

*Experiment 89.* UNDER WHAT CONDITIONS WILL A DRY CELL HEAT A WIRE RED-HOT? Stretch a piece of fine (No. 30) bare copper wire two feet long between two nails driven in a board. Attach two pieces of larger insulated copper wire (at least No. 18) two feet long to the binding posts of a dry cell (Figure 403). Be sure the ends are scraped clean. Press the free and bare ends of the two insulated wires against the small wire near the ends. Have someone test the temperature of the small wire with his fingers.

Gradually slide the large copper wires closer together along the small wire. Notice that the small wire soon becomes hot where the electricity is flowing through it. After it becomes too hot to hold, continue to move the ends toward each other. Does the small wire become red-hot? Do the insulated wires become hot at all? Can you explain the difference?

You found in your experiment that you could heat a small wire red-hot if you made it short enough. While the small wire became red-hot, the larger wires were slightly warm. The same current was flowing in both wires. Why did it heat one wire more

FIG. 403. Apparatus to show how electricity heats a wire

than the other? To understand this problem you need to know which wire has the more electrical friction, or resistance, per inch. In other words, is it harder for the electricity to get through an inch of small wire or an inch of large wire of the same material? Clearly, it is harder to get through a small wire; that is, the small wire has a greater resistance per inch. Therefore, a given electrical current makes more heat where the resistance is great than where it is small; so the small wire became hotter than the large wire.

But there is another problem to solve. Why did the small wire not get red-hot when the current went through a long piece of it? You can answer this question for yourself if you will think carefully. If the electrical pressure is kept the same, will more electricity flow through a long wire or through a short one of the same diameter? Through a short one, of course. The longer the wire, the more resistance there is. The resistance, or electrical friction, in the longer wire therefore allows less electricity to get through. When less electricity is flowing, less heat is made in each inch of wire. As you slid the two larger wires together, more and more electricity flowed through the small wire, until there was enough to heat it red-hot.

From this experiment you can remember three important facts: (1) When the same amount of electricity is flowing through several wires, the one with the most resistance will be heated most. (2) When much electricity is flowing through a wire, the wire is heated more than when only a little is flowing. (A current twice

FIG. 404. Four common electrical heating devices are shown in this picture: a heater, a toaster, a heating pad, and an iron. The electric fan helps keep us cool, and the electric clock tells us the time of day.

as large as another really produces four times as much heat, while the same current passing through a resistance twice as large as another produces only twice as much heat.) (3) For each electrical situation there is a certain length of wire that will become red-hot or white-hot. Table 18 gives the resistance of several metals and alloys (mixtures of metals) compared with silver.

TABLE 18. ELECTRICAL RESISTANCE OF SOME COMMON METALS COMPARED WITH SILVER

| METALLIC ELEMENTS | | ALLOYS USED IN ELECTRICAL DEVICES | |
|---|---|---|---|
| Silver | 1.00 | Manganin | 27.67 |
| Copper | 1.11 | Constantin | 30.82 |
| Aluminum | 1.78 | Nichrome | 62.89 |
| Tungsten | 3.52 | | |
| Iron (soft) | 6.29 | | |
| Platinum | 6.29 | | |
| Mercury | 60.24 | | |

The designer of an electric toaster or iron first selects wire of high resistance and then experiments to find out the proper size and length for the kind of toaster or iron he is designing. When he has the right length of heating wire, the designer coils it about some electrical insulator. The most common insulators for this purpose are mica and porcelain. Mica is a transparent mineral

FIG. 405. The heating element in an electric toaster

FIG. 406. The heating element in an electric iron

that splits into thin and somewhat flexible sheets. Sometimes it is called *isinglass*. Porcelain, as you know, is a kind of artificial stone made by baking clay. When the heating wire, or *heating element*, has been properly mounted on the insulating material, it is placed in the iron, toaster, or other heating device. When the current is turned on, the electrical current flows through the copper wires, but heats them very little. When it reaches the high-resistance wire, much heat is produced.

*Self-Testing Exercises.* 1. What change of energy takes place in an electric iron; that is, what kind of energy changes into what kind?

2. Tell how an electric toaster is constructed. Why is a wire with high resistance used?

3. Explain why the heating wire in an electric toaster becomes much hotter than the copper wires that bring the electricity to the toaster.

*Problems to Solve.* 1. A wire that is supposed to become red-hot does not do so when it is connected in an electrical circuit. State two changes that might be made to have the wire heat properly.

2. Why do you think most wires and transmission lines for carrying electric current are made of copper or aluminum?

3. Examine as many electrical heating devices as you can to find out how the heating element (wire) is arranged in the space provided. What insulating materials are used in these devices?

4. Can you buy wires to put in electric heaters and toasters? Inquire at electrical, hardware, and ten-cent stores. If you can find some, try to learn of what metal or alloy they are made.

HOW DO ELECTRIC BULBS PRODUCE LIGHT? Today we use electric light-bulbs of many sizes, from tiny flashlight bulbs to the huge bulbs that illuminate aeroplane beacons and lighthouses. Some glow at an electrical pressure of only one or two volts.

Others must have 6, 32, 110, or more volts to give light. Most of these bulbs use the principles you learned while you were studying electric heaters. An ordinary light-bulb contains a wire that glows because it becomes white-hot, or *incandescent*. These light-bulbs are called incandescent bulbs. To be successful, the wire in a bulb must have the right resistance, it must not melt, and it must not oxidize or burn.

FIG. 407. Edison's first electric lamp

About sixty years ago (in 1880) Thomas Edison made the first successful incandescent lamp. For a wire, or *filament*, he used a small thread of carbon. Carbon does not melt or evaporate rapidly until it reaches a temperature above 5000° F. Thus it could be heated very hot without melting the filament. However, carbon burns rather easily. To prevent the filament from burning, Edison had it sealed inside a glass bulb. Then he pumped the air out and sent an electric current through the filament. Edison's carbon-filament lamps had a number of disadvantages. The carbon filament used much electrical energy to produce a little light. In fact, about 99 per cent of all the electrical energy became heat instead of light. Thus, gradually, the filament evaporated, and the carbon darkened the glass bulb. In spite of these disadvantages, carbon-filament light-bulbs were for thirty years the best that could be bought.

Today the filaments of our light-bulbs are made of tungsten. Each tiny tungsten wire is formed into a very close spring-like coil so that each turn of wire helps keep its neighbors hot. The glass bulbs are filled with the gas argon. Argon is a very inactive chemical element; that is, it does not combine easily with other substances. Therefore it does not change the tungsten. It is put into the bulb to keep the tungsten from evaporating as rapidly as it would in a vacuum. These improvements allow us to get seven times as much light from electricity as could be got with a

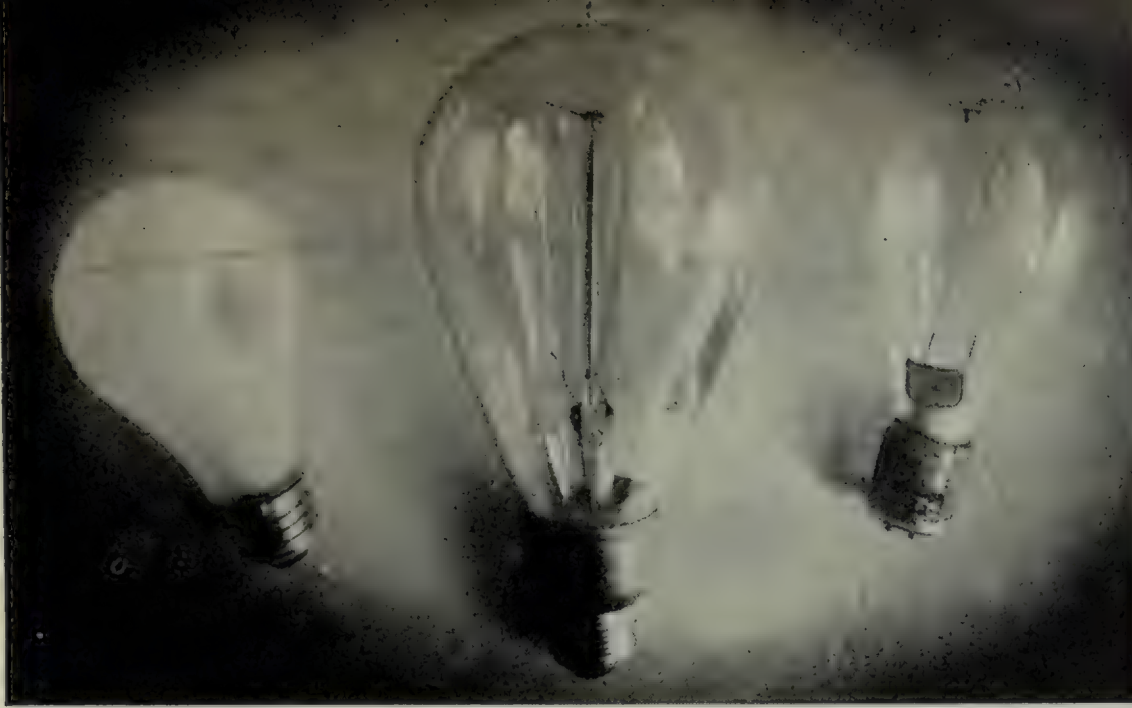


FIG. 408. At the right is an early kind of carbon-filament electric lamp. At the left are two modern tungsten-filament lamps, one of them with a frosted-glass bulb. (Westinghouse photo)

carbon-filament bulb. But still we receive less than five per cent of the electrical energy in the form of light. Our light-bulbs are better heaters than "lighters."

Our city streets are filled with color by lamps of still another kind. These lamps are in the form of tubes that glow with red, blue, or green light when electrical current passes through them. The tubes are bent into all sorts of shapes to make attractive signs. We commonly call them *neon* signs, because the red ones really contain the gas neon. These "tube" lamps have no filaments at all. They contain very small amounts of gas. A special electrical transformer sends electricity through the gases with a pressure of thousands of volts. The electrons, striking the molecules of gases, cause the molecules to give out light. Each different gas gives out its own color of light. Figure 409 shows a *fluorescent* lamp. This new type of lamp gives more light with less heat than an incandescent lamp.

*Self-Testing Exercises.* 1. Draw a diagram to show how an incandescent light-bulb works. Show in your diagram the glass of the bulb, the filament, the connecting wires, and the vacuum or gas in the bulb. Label each part and tell what it does.

2. (*a*) What material was used for the first successful incandescent light-bulbs? (*b*) What material is used now? Why?

3. What is the main disadvantage of the electric light-bulbs we use most commonly?

4. Explain how a neon sign works.

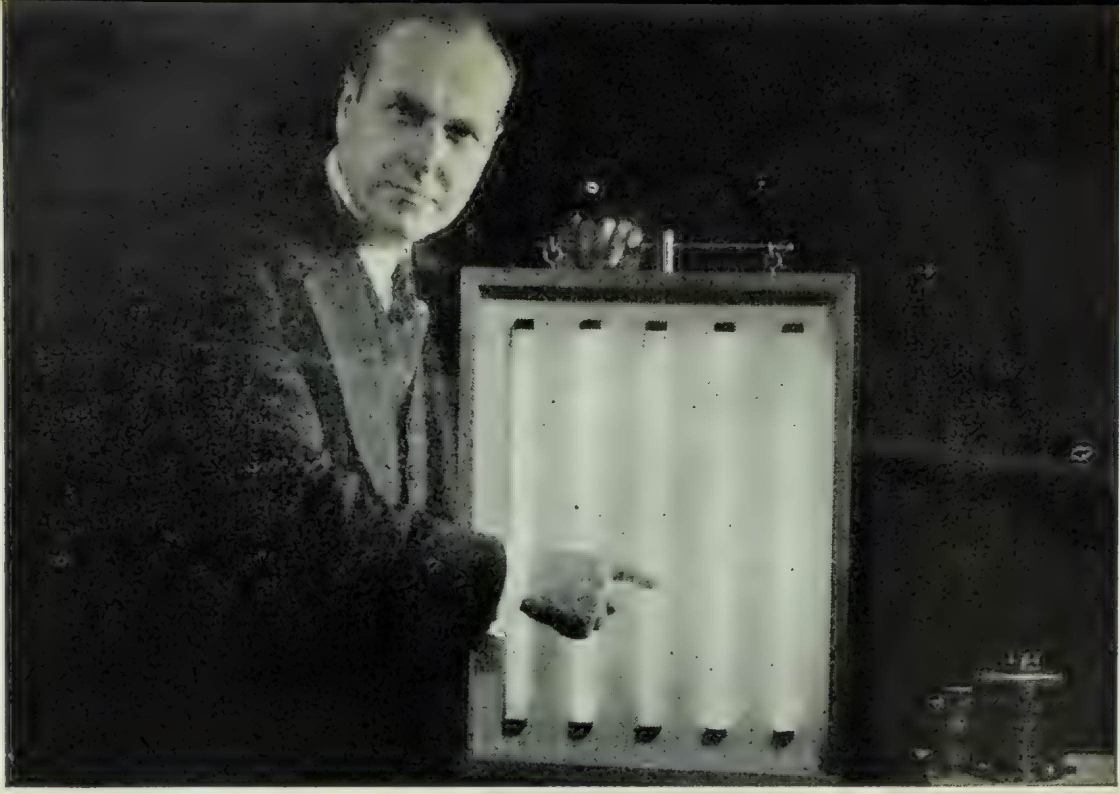


FIG. 409. This new kind of lamp, which has no filament, is called a fluorescent lamp. The glass tubes glow when current flows through a gas they contain. The insides of the glass tubes are coated with special materials. These materials make such a lamp give as much as 120 times the illumination for the same amount of current consumed by a filament lamp. Furthermore, when they are lighted, these fluorescent lamps are much cooler than filament lamps. (General Electric photo)

*Problems to Solve.* 1. Find out how electric arc lamps work.

2. Get a "burned-out" light-bulb. With a pair of pliers or other tools remove the base of the bulb. Find the wires that connect the base with the filament. How are they insulated from each other? Where is the tube through which the air was pumped out of the bulb? Wrap the bulb in a piece of heavy cloth, and break it to get a piece of the filament. Is it straight or coiled?

3. Read in reference books about one or more of the following: electric furnaces, Thomas A. Edison, electric heating, electric welding. Be ready to make a report on your findings.

## ¶ 7. How do electrical currents do work?

WHENEVER WE THINK OF ELECTRICITY DOING WORK, we think of electric motors. In homes electric motors furnish the force to sweep the floors, run refrigerators and fans, whip cream, mix cake, operate sewing-machines, and drive toy locomotives. On farms they grind grain, sharpen tools, milk cows, and pump water. They run all sorts of machinery in factories, stores, and pumping stations. They start automobile and aeroplane engines and drive street-cars, electric locomotives, streamline trains, and ocean liners. Our country would be in serious trouble for a long

time if all its electric motors should be destroyed. Your main problem now is to find out how these important electrical machines are turned by electric current.

HOW DOES AN ELECTRIC WIRE ACT NEAR A MAGNET? To understand how a motor works, you will need to know how a wire carrying a current acts when it is in the magnetic field between the poles of a magnet. You will want to see for yourself this strange action of the wire.

*Experiment 90.* HOW DOES AN ELECTRIC WIRE MOVE IN A MAGNETIC FIELD? (*a*) Arrange a strong U-magnet, a dry cell, a push-button, and a length of No. 30 insulated wire as shown in Figure 410. Be sure that the wire which hangs between the ends of the magnets is loose and free to move. Press the button. What does the wire near the magnet do? Release the button and repeat the experiment to make sure you were correct in what you decided about the action of the wire.

*b*) Now change the wire so that the current goes through it in the opposite direction, that is, change the connections on the battery. Press the button again and notice what the wire does.

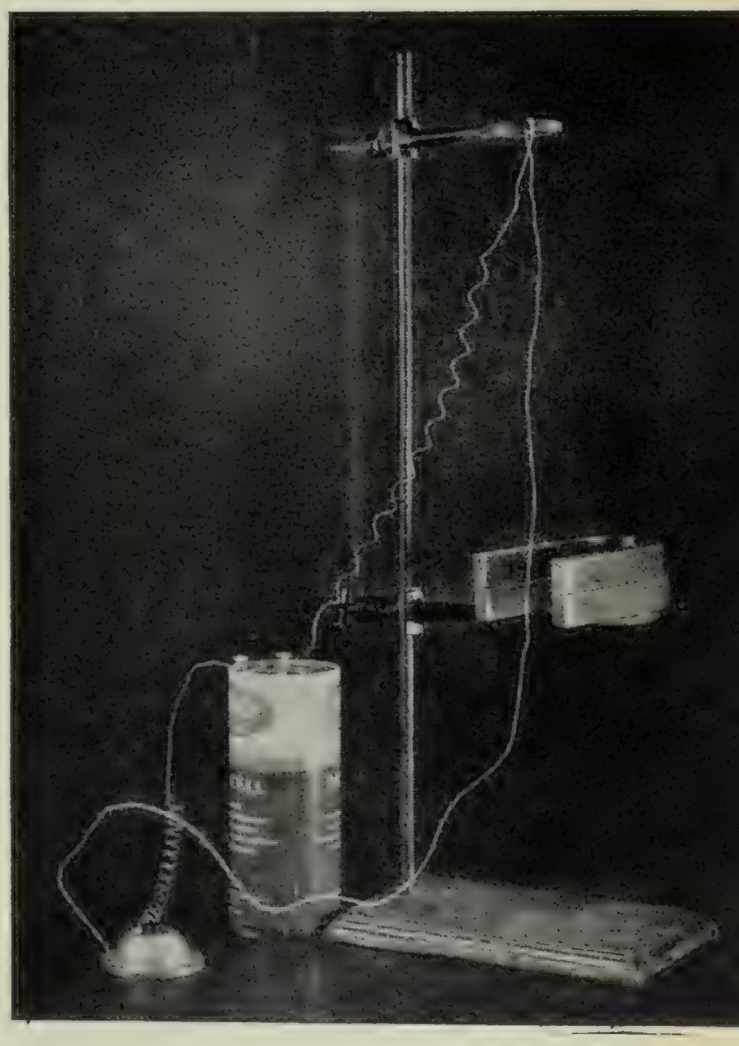


FIG. 410. Apparatus for Experiment 90

From this experiment you realize the truth of a law discovered a long time ago by Michael Faraday: A *wire carrying a current tends to move when the wire is in a magnetic field.* The full statement of the law tells just which way the wire moves in the magnetic field. But all you need to know is that the wire moves in one way when the current flows in one direction and in the other way when the direction of the current is reversed. When you know these facts, you can understand why an electric motor can be made and how the magnets and the armature of the motor work together to run machinery.

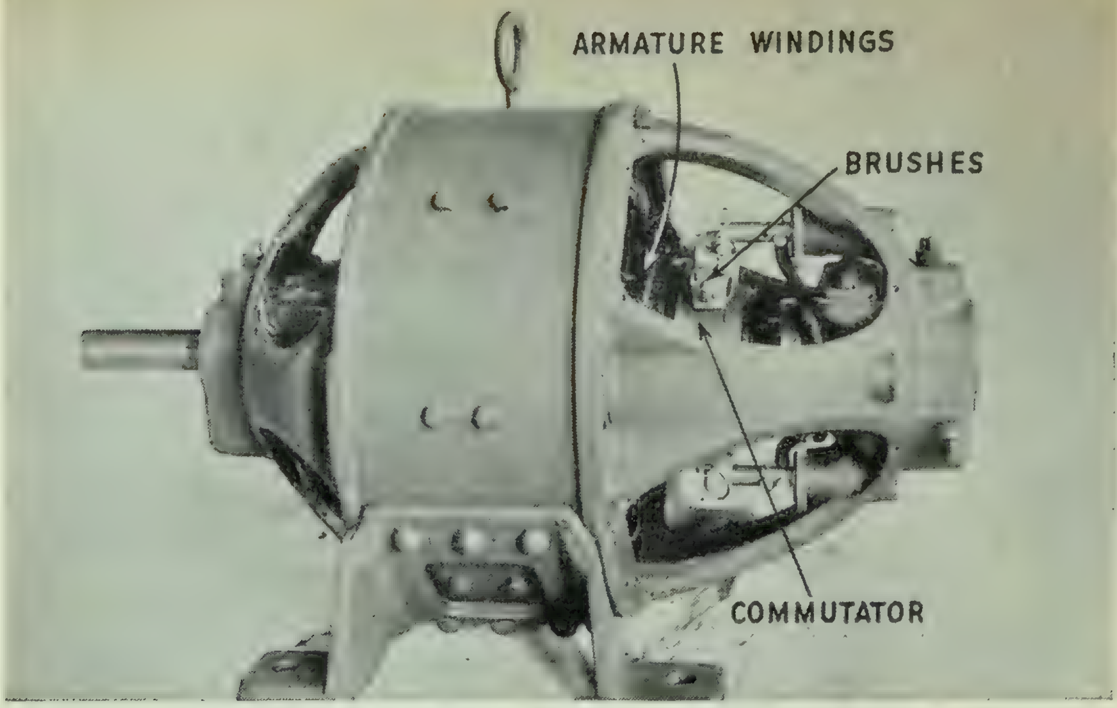



FIG. 411. A direct-current electric motor. *Armature windings* means the thousands of feet of wire that are wound around a core to make the armature. (Westinghouse photo)

HOW DOES AN ELECTRIC MOTOR WORK? Each electric motor has two important parts, the field magnets and the armature. As you can guess, the field magnets are needed inside the motor to make a strong magnetic field. Just as in the bell, the armature is the part of the motor that moves. Small motors of the kind that you can make easily have two other parts, the commutator and the brushes. Acting together, the commutator and the brushes carry current to the wires on the armature. The generator that you studied in Figures 401 and 402 had a commutator and brushes to carry the current it produced from its armature to a circuit outside the generator. If you are reasonably careful, you can make a small electric motor that will really run, as described in Experiment 91.

*Experiment 91.* HOW IS AN ELECTRIC MOTOR CONSTRUCTED? For the field magnets of your motor use one or two large U-magnets like those you used in Experiment 90. For the armature get a cylindrical cork or piece of soft wood about two inches long and an inch in diameter. Cut two shallow lengthwise notches on opposite sides of the wood or cork cylinder. Wind about twenty turns of No. 22 or No. 24 insulated wire in these notches (Figure 412). Tie a thread around the middle of the cylinder over the wires to hold them.

Now cut two small pieces of No. 18 bare copper wire about an inch long, or get two nails about that size. Push them into the cylinder at the points shown in Figure 412; fasten one free end of the wire to each bare wire (or nail). Get a large needle or two nails for the

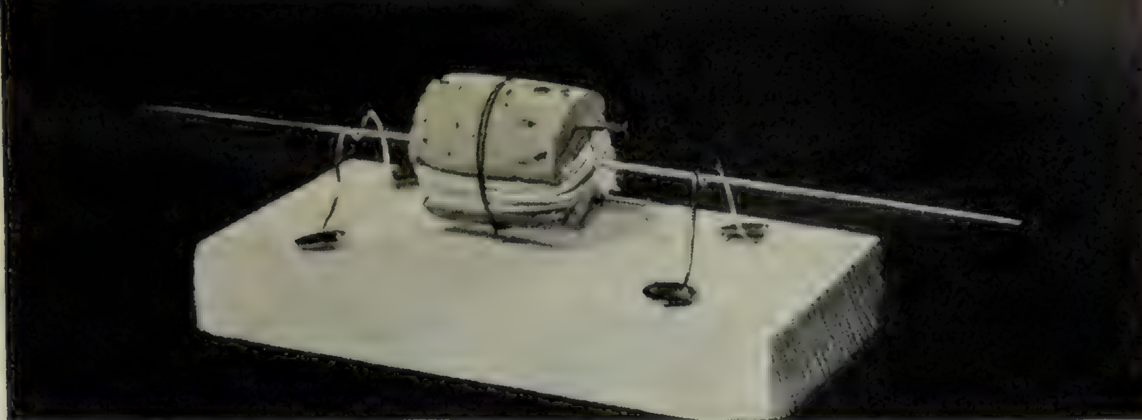


FIG. 412. Armature of a home-made motor

shaft and some bent wires for bearings. The armature will work better if it is balanced so that it will stand in any position.

Place the field magnet (or magnets with N-poles together) over the armature, as shown in Figures 413 and 414. Set the armature coil horizontal. Connect copper wires to one or two dry cells, uncover the ends, and hold them as shown in the figure. When the wires from the cells touch the wires on the armature, the armature should start turning and continue until you remove the wires. Sometimes it may be necessary to have someone give the armature a turn to start it. You may need to practice a little to learn just how to hold the wires. With a little thought you can probably work out a way of fastening the connecting wires on nails or screws so that you will not need to hold them.

FIG. 413. A home-made electric motor

In a home-made motor like the one shown in Figure 413, the "pins" to which the armature wires are fastened make the commutator. The wires held in the hand are the brushes. Let us see why the motor starts turning and continues to turn. The reason for its starting is easy to understand.

The wires of the armature coil act just like the wires in Experiment 91. The electric current going in one direction in all wires on one side (at A in Figure 414) causes that side to be pulled upward through the magnetic field. The same current going in the other direction on the other side of the coil causes that side to be pulled downward. With one side being pulled up and the other side down, the coil starts to turn.

But just as the armature gets a good start, the commutator pins move away from the brushes. Inertia keeps the armature turning until the pins strike the brushes again. Now the pins are reversed, and side A, which was pulled upward, is pulled downward. Side B, which was pulled downward, is pulled upward until the "pins" leave the brushes again. Then the whole process is repeated for every revolution of the armature.

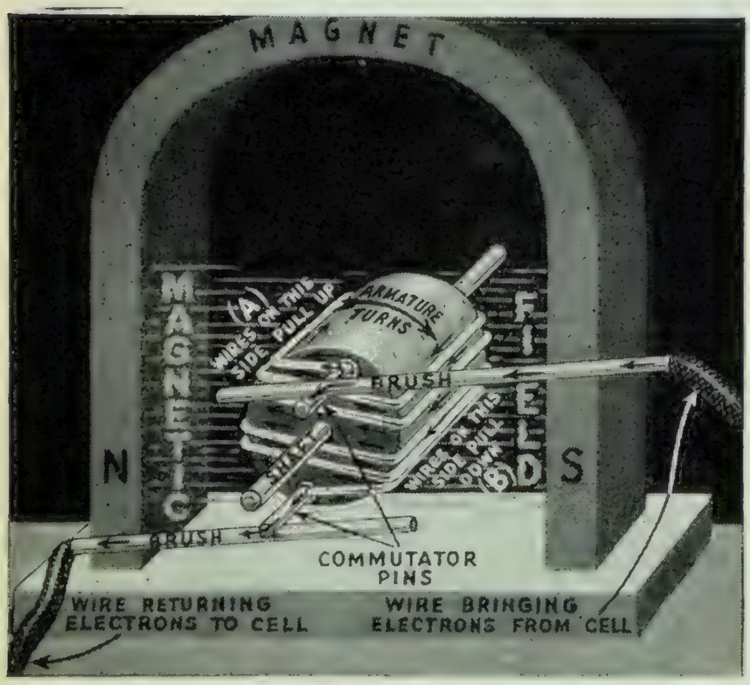



FIG. 414. Study this drawing carefully to see how electrical current operates the home-made motor.

One trouble with your toy motor is that it does not pull steadily. When the wires are at the top and bottom, they cannot pull. You could improve it by adding another coil at right angles to the first, or even three coils evenly spaced around the cylinder. Then at least one set of wires would be pulling all the time. Another improvement would be to make the commutator in the form of a smooth ring cut into pieces, as shown in Figure 415. Then the brushes would slide smoothly along and be touching the commutator constantly while the commutator is whirling around.

Modern electric motors use all these ways of improving the armature. The wires are wound on the armature in such a way that all the wires on one side are always pulling up, and all those on the other side are always pulling down. Another way of improving a motor is to use powerful electromagnets to form the magnetic field. The poles of these magnets are set very close to the metal armature. In this way the magnetic field inside the motor is made very strong. The best motors change about 90 per cent of the electrical energy they use into kinetic energy for doing work. Motors of many different sizes and kinds are made. Some of our smallest motors drive electric clocks. At the opposite extreme in size are the motors that drive ocean liners. Some of these giants have 40,000 horse-power.

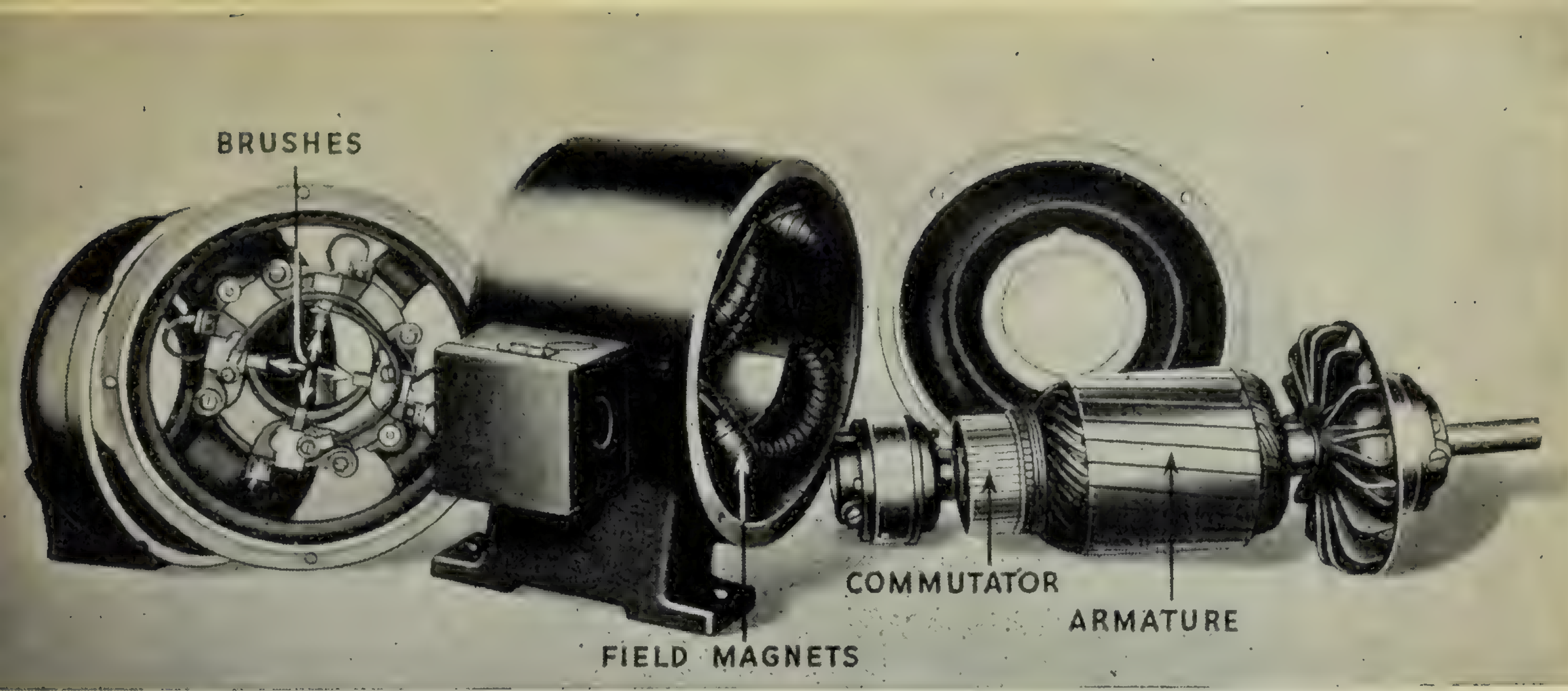



FIG. 415. Parts of a motor to show brushes, field magnets, commutators, and armature (Fairbanks Morse photo)

HOW IS THE SPEED OF A MOTOR CONTROLLED? To make a steam-engine go faster, you let more steam into the cylinders. To make a gasoline engine go faster, you let more gasoline into the cylinders. Now that you have learned about electrical resistance, you can understand one way of making electric motors go faster or slower. A device called a *rheostat* (Figure 416) regulates the speed of motors by regulating the strength of the electric current. This is done by increasing or decreasing the resistance in the circuit. The rheostat contains many coils of wire through which the current may flow. The greater the number of coils through which the current must flow, the less the current that can flow.

By moving the arm of the rheostat to the right or to the left, the current is made to pass through fewer or more of the coils of wire. In this way the resistance to the current of electricity is decreased or increased. This decreases or increases the strength of the current that flows to the motor, thus making the motor go faster or slower. The stage lights in your school auditorium are probably controlled by rheostats. There are other kinds of devices for controlling the speed of motors, such as those on toy electric trains operated by transformers.

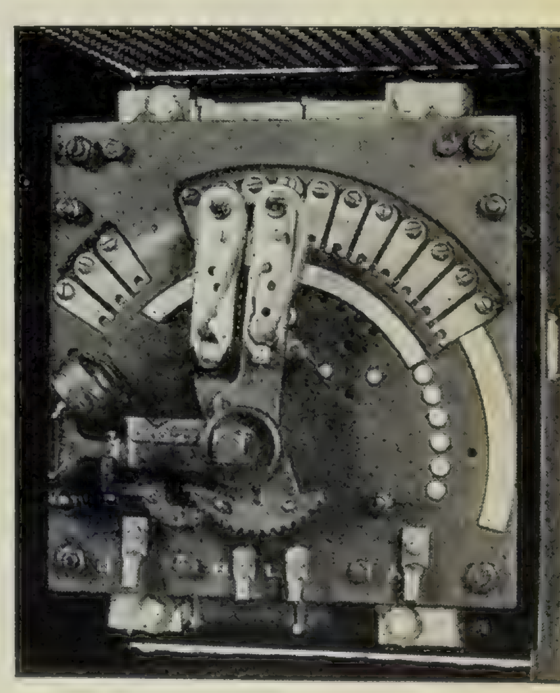


FIG. 416

*Self-Testing Exercises.* 1. What does a wire in a strong magnetic field do when an electrical current is sent through the wire? When the current is sent in the reverse direction?

2. Why does an electric motor need to have field magnets to make it run?

3. Explain why the armature of an electric motor turns when electrical current is sent through it.

4. What is the purpose of brushes and a commutator?

5. Why do the armatures of electric motors have several coils of wire on them?

6. Why are there many wires in each coil?

7. Explain how the speed of electric motors can be regulated.

*Problems to Solve.* 1. Electric clocks and some phonographs are run by *synchronous* motors. Find out what these motors are. If possible, get a worn-out electric clock and take it apart to study it.

2. Read in reference books to find how an *induction* motor works without brushes and a commutator.

3. What advantage can you find for using electromagnets rather than permanent magnets in motors?

4. Find an electric motor that you can examine. Locate each important part named in the problem.

5. Electric motors run very rapidly. What ways can you find for slowing down the movement they produce; that is, how could you make a machine attached to a motor run more slowly than the motor? Think of what you learned about simple machines.

6. Make a diagram to show how the field magnets and armature of a motor could be connected so that both armature and field magnets would receive current from one pair of wires. Does your plan connect them in series or in parallel? Is the other plan possible?

7. Read in reference books to find how the motorman or engineer controls the speed of street cars and electrically operated railroad locomotives.

## ¶ 8. How is the energy of electrical current transmitted from the generators to our homes?

WHAT PROBLEMS MUST BE SOLVED IN TRANSMITTING ELECTRICAL ENERGY? We are so accustomed to using electricity whenever we need it that we often pay little attention to where it comes from. You may not know, for example, where the electricity you use is produced. Many towns and cities get their electricity from power-plants in or near the town. Some cities, however, obtain their electrical energy from power-plants located hundreds of miles away, where there are natural waterfalls or

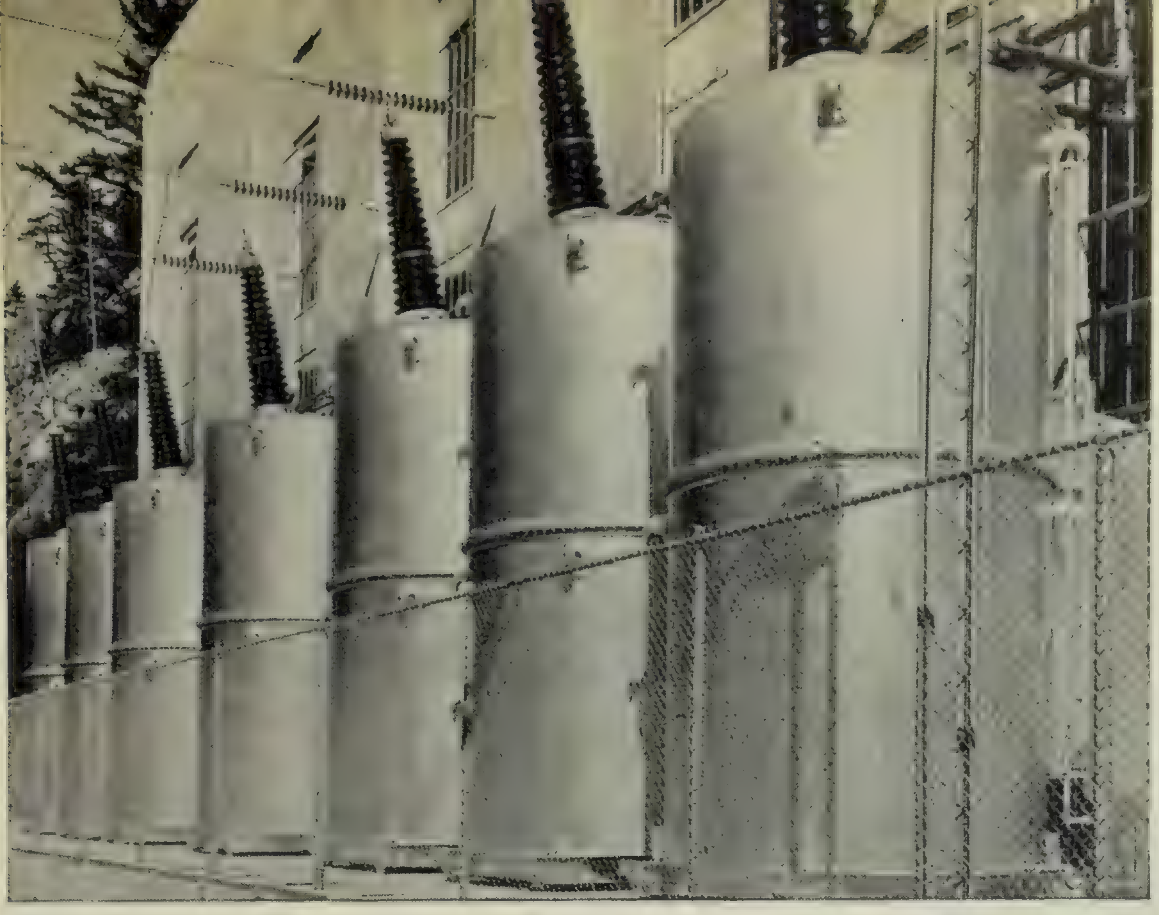


FIG. 417. Step-up transformers at a great power plant. The generators at this plant generate electricity at a pressure of 13,800 volts. These transformers raise the pressure of the electric current to 222,000 volts before it is sent over the wires to heat the irons and stoves and light the houses and streets of a large city. (Westinghouse photo)

where power dams have been built in rivers. In travelling across the country you have probably seen the tall steel towers that support cables of copper or aluminum through which the electricity is transmitted. These cables are attached to huge insulators that keep the electric current from leaking off into the ground. If you ever stopped to examine one of these towers more closely, you probably saw a sign, "Danger—100,000 Volts" or "Danger—High-Tension Wires."

If electrical wires come to your home, you probably know that the current you use has a pressure of about 110 volts. When electricity is transmitted for long distances, it is necessary to use a much higher voltage. Let us see why. First of all, the longer the conductor, the greater the resistance offered to the passage of the current. A larger electrical pressure is therefore needed to force the current over long distances than over short distances. Second, you will remember that in overcoming this resistance a part of the electrical energy is changed to heat energy. This energy is, of course, lost. Third, you remember that the greater the amount of current flowing through the wire, the greater the amount of electrical energy that is changed to heat.

The problem of the electrical engineer is to transmit the electrical energy with as little loss as possible. To reduce the amount of electrical energy changed to heat, it is necessary to keep the amount of current as low as possible. You will remember that the power as measured by watts is equal to volts times amperes (page 546). To keep the amount of current low and still get the same power, it is necessary to increase the voltage. For example, with a voltage of 200 and an amperage of 100 the total amount of power transmitted is 20,000 watts. A voltage of 20,000 and a current of 1 ampere will also transmit 20,000 watts. But in the second case only $\frac{1}{10,000}$ as much energy will be lost. By keeping the voltage high and the amount of current low, only a very small amount of electricity is lost by being changed to heat.

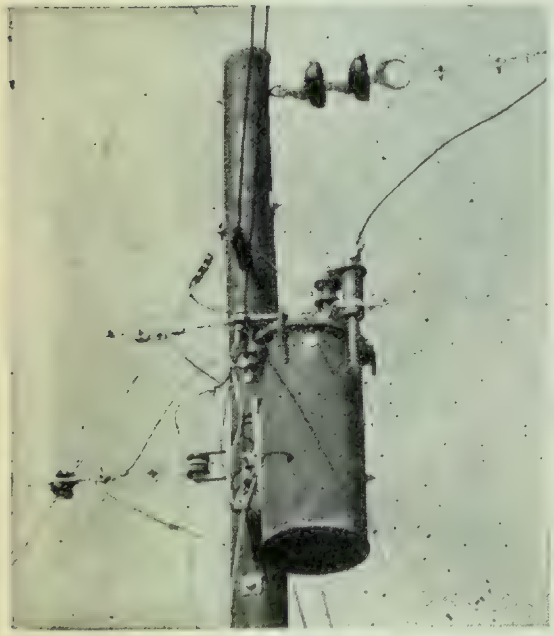


Fig. 418. A pole transformer (Westinghouse photo)

The second problem of the engineer is that of securing the high voltage necessary for long-distance transmission of power. The generators used at Niagara Falls produce electricity at a pressure of 12,000 volts. Too much current would be lost in transmission over long distances at this voltage; so the current is changed by raising it to 60,000 volts before it is sent out over the transmission wires. How is this done?

How do transformers change the voltage of a current? The device used to change the voltage of a current is called a *transformer*. You probably have seen a black box on one of the electric-light poles near your home. In this black box is a transformer (Figure 418). Travelling through the country you may have seen the transformers used for long-distance transmission of electricity. The small black box used to operate an electric train also contains a transformer.

To understand how a transformer works, you will need to recall what you learned about the operation of a dynamo. In Experiment 91 you saw that a current was produced when a coil of wire was rotated between the poles of a magnet. When this was done, the coil of wire cut across the lines of force between


FIG. 419. Apparatus for Experiment 92

the poles of the magnet. When the coil was stationary, no current was produced. The same idea is used in a transformer.

*Experiment* 92. HOW IS A TRANSFORMER MADE? Obtain a soft iron rod and bend it into a circle about three or four inches in diameter. (A core of soft iron wires may be used equally well.) Wrap two coils of about fifty turns each of wire around the core (Figure 419). Connect one coil in series with a switch and two or three dry cells. Connect the other coil to a galvanometer. Now close the switch. What happens? Now open the switch. What happens? What change takes place in the direction of the current as the switch is opened and closed?

Your experiment showed that a current is produced in the coil connected with the galvanometer when the circuit is closed. When the circuit is broken, a current is also produced, but this time in the opposite direction. Now let us think of the kind of current produced by an alternating-current generator. You remember that the current first flows in one direction; then it dies down to zero and flows in the opposite direction. When an alternating current is sent through one coil of a transformer, the lines of magnetic force first cut the second coil in one direction; then, as the current reverses, they cut the coil in the other direction. In other words, the changing magnetic field has the same effect as if the second coil were being moved. The result is that an alternating current is produced in the coil.

Now that you see how a transformer works, you can understand how it can be used to change the voltage of the current. Suppose that we want to increase the voltage. The generator producing an alternating current is connected with one of the

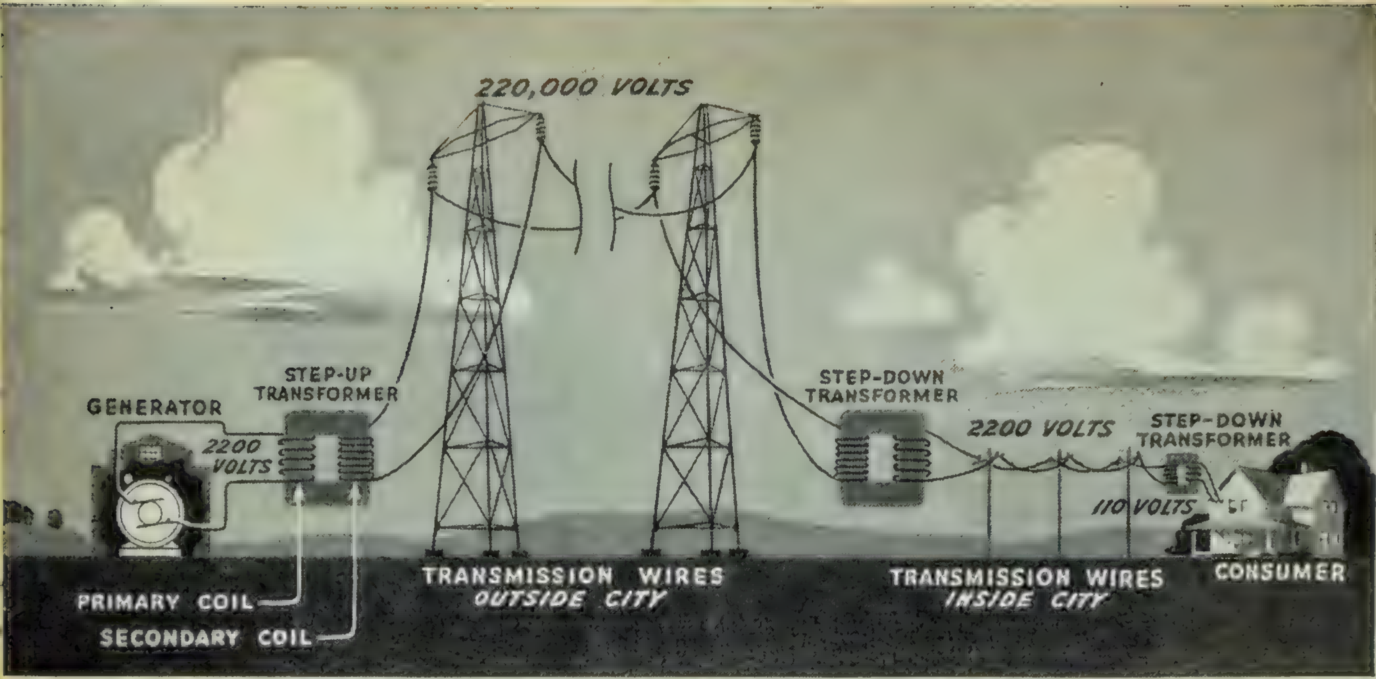



FIG. 420. This diagram will help you understand how a step-up transformer increases voltage for transmission and how a step-down transformer reduces the voltage for everyday uses.

coils around the armature. This coil is called the *primary coil.* We will suppose that there are 100 turns of wire in the primary coil. The *secondary coil* that is connected with the transmission lines has many more turns, say 2000 turns. The lines of force from the primary coil thus cut through twenty times as many turns in the secondary coil. The result is that the voltage in the wires attached to the secondary coil is twenty times as high as that in the primary coil. It has been increased, or "stepped up." If there were 110 volts in the primary coil, the voltage of the secondary coil would be 2200.

You must not forget, however, that the total amount of power in the secondary coil is the same as in the primary except for the loss of about three per cent as heat. If the primary coil carried 100 amperes at 110 volts, the secondary would have a voltage of 2200, but the current strength would be only five amperes. You can see why this must be true by the following figures:

Power in primary coil: 110 V$\times$100 A$=$11,000 watts.

Power in secondary coil: 2200 V$\times$5 A$=$11,000 watts.

By using *step-up* transformers, the electrical engineers can raise the voltage and lower the amperage. This greatly reduces the loss of energy. However, very high voltages cannot be used because energy is lost in other ways. Most city power stations use generators that produce current at 2200 volts. Such a large voltage cannot be used safely in the home; so it must be reduced. This is done by a *step-down* transformer. In a transformer of this kind the number of turns of wire on the primary is twenty times

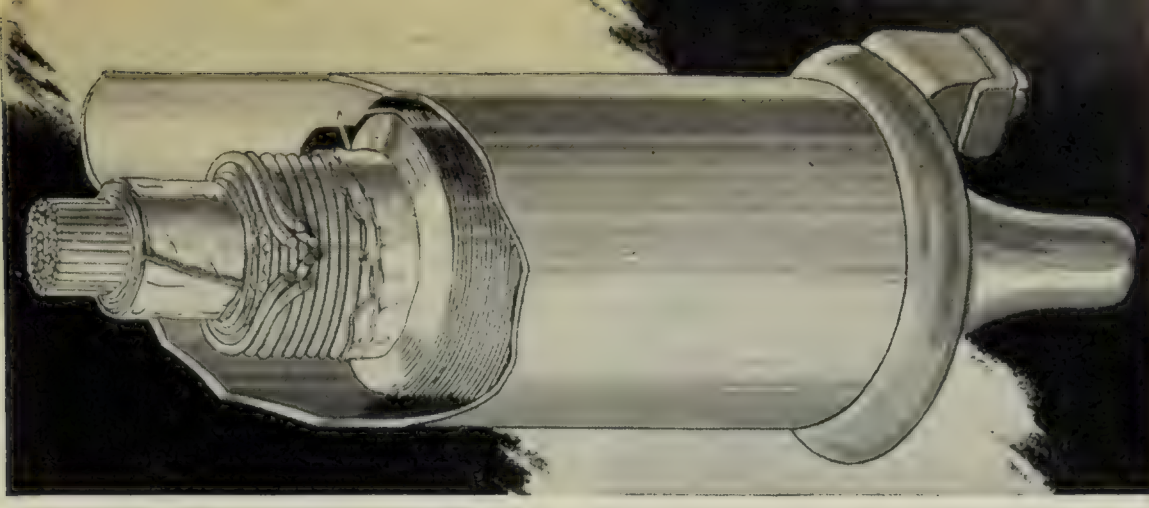


FIG. 421. A cut-away view of the kind of induction coil used in low-priced automobiles. You can plainly see the primary and the secondary coils.

as great as on the secondary. In such a transformer the voltage would be stepped down to 110 volts in the secondary coil. At the same time the number of amperes would be twenty times as great as in the primary coil. The small transformers used to operate bells and toy electric trains reduce the pressure of the 110-volt house-lighting current to 5, 10, or 15 volts.

The spark-plugs in your automobile are connected to a special kind of transformer called an *induction coil.* In an induction coil the primary coil is placed inside the secondary coil. Since the battery of the car furnishes direct current, it is necessary to make and break the current, as you did in Experiment 92, in order to change the magnetic field and thus produce a current in the secondary coil. To do this a circuit breaker is used. This is connected to the engine, and it makes and breaks the circuit each time a spark is needed.

To force the spark across the gap in the spark-plug, a pressure of 3500 to 15,000 volts is needed. In order to get this pressure, the primary coil is wound with 150 to 250 turns of comparatively large copper wire, which is connected with the six-volt storage battery. The secondary coil is wound with about 20,000 turns of fine copper wire. The total length of the wire on these two coils amounts to over a mile.

*Self-Testing Exercises.* 1. Why must the electrical pressure (voltage) of a current be increased when the current has to be transmitted a long distance?

2. How does a step-up transformer increase electrical pressure?

3. How does a step-down transformer operate?

4. What does the induction coil of an automobile do? Is the longer wire in the induction coil connected to the battery or to the spark-plugs?

## Looking Back at Unit 16

1. Turn to the table of contents where the problems of this unit are stated. Copy each problem. Then answer it in about one-half page. Be sure to include in your answers the really important ideas.

2. Show that you know the meaning of the following words:

| | | |
|---|---|---|
| *conductor* | *galvanometer* | *positive charge* |
| *electron* | *generator* | *series circuit* |
| *fuse* | *short circuit* | *alternating current* |
| *field magnet* | *insulator* | *storage battery* |
| *ammeter* | *electrical current* | *parallel circuit* |
| *ampere* | *volt* | *watt* |
| *armature* | *watt-hour meter* | *transformer* |
| *circuit* | *resistance (electrical)* | *magnetic field* |
| *proton* | *electromagnet* | *induction coil* |
| *electrode* | *rheostat* | *voltmeter* |

## Additional Exercises

1. Suppose that an electric bell rang very feebly. What might be the matter with it?

2. Find out why a special circuit is usually put in a house when an electric range is installed.

3. Find out the rate per kilowatt-hour in your city. Then figure out how much it costs to light your living-room for three hours.

4. Why will you get a shock if you touch the spark-plugs while an automobile engine is going?

5. Find out how the electrical system of an automobile is constructed so that it generates its own power, lights the lamps, turns over the starter, and supplies a spark to the spark-plugs.

6. Find out why direct-current generators rather than alternating-current generators are used on automobiles.

7. If there are any high-voltage lines near your city, find out the voltage at which the current was generated and the voltage sent through the line.

8. In reference books read about the discoveries of André Ampère, Alessandro Volta, and Michael Faraday.

9. Can a wire be moved through a magnetic field in any way without causing electrons to flow? If so, how?

10. Why does the needle of the galvanometer described in Experiment 87 move when a current goes through the coil? To answer this exercise, read in reference books to find how galvanometers work.

11. Is the electrical resistance of a small wire more or less than that of a large wire?

12. Make a study of electrical insulators. What materials are used? What are their shapes? Why are they made of these materials in these shapes?

13. Find out how storage batteries are used in submarines.

14. Make a diagram of a circuit by which a bell will be rung by a push-button either at the back door or at the front door.

15. Work out a diagram of a circuit so that a bell in the kitchen and a bell upstairs would both be rung by the button at the front door.

16. Work out a diagram of a circuit by which the button at the back door will ring a buzzer and the one at the front door will ring a bell, but only one battery will be used for both.

17. A metal plate with a positive charge and another with a negative charge are placed in a solution that contains both positive and negative particles. Why will the positive and negative particles be separated?

18. Learn from reference books how objects are plated by the use of electricity, that is, electroplated.

19. How is water decomposed into hydrogen and oxygen by the use of electricity? You will find explanations in reference books. Look under "Electrolysis."

20. From a physics book learn the rule that tells the direction in which a current will flow in a generator coil. (In physics books it is customary to say that the current flows from positive to negative. The electrons really flow in the opposite direction.)

21. Learn from reference books how an "electric eye," or *photoelectric cell,* works and how "electric eyes" are used.

22. Read about *induction machines* or *electrostatic machines*. How do they work?

23. Electricity can really be stored in a *Leyden jar*. Find out what a Leyden jar is and what can be done with it.

## Books to Read

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FROM THIS QUEER-LOOKING "BEDSPRING" AERIAL on a hilltop in New Jersey a radar beam was directed at the moon January 10, 1946. Less than two and one-half seconds later sensitive instruments received a response. Travelling at a speed of 186,000 miles a second, radar waves hit the moon and bounced back to earth like an echo. They made the round trip of 470,000 miles faster than you can read about it. Radar, developed from radio, is one of the newest means of communication. Before scientists could work out modern methods of communication, they had to study sound. Then they had to discover how to change the energy of sound into electrical energy. (U.S. Army Signal Corps photo)

# UNIT 17

# How Do We Use Energy for Communication?

## Looking Ahead to Unit 17

PROBABLY THE FIRST THING YOU HEAR in the morning is the alarm clock. You lie in bed half awake and half asleep, undecided whether to get up. Your mother does not hear you getting up; so she decides to come and see about you. You hear her coming and get up before she gets there. You hear sounds which tell you that the rest of the family are up. Soon your mother calls you to breakfast. At breakfast you listen to the family talk. Your father asks you if you have prepared your lessons, and you join in the conversation by replying. Before you realize how much time has passed, the clock strikes. This tells you that you must hurry, or you will be late for school.

These are but a few of the ways in which sounds have affected your life during a single day. They told you when to get up, when to cross the street in safety, and when to play. By sound you communicated with other people and received their thoughts. It helped you learn things and enjoy them.

Since a very early time man has sought ways of sending messages over long distances with greater and greater rapidity. Messengers and written messages have been sent with increasing speed as the runner and pony express have given way to the railroad and aeroplane. Very soon, however, men saw that certain forms of energy, such as sound and light, travelled more rapidly than man could hope to carry his messages. Thus, some savage tribes developed drums powerful enough to send sound from village to village; others invented smoke and light signals. By these means man began to *transmit* his messages.

When electric currents and ways of producing them were discovered, thinking men saw in this form of energy a new and more

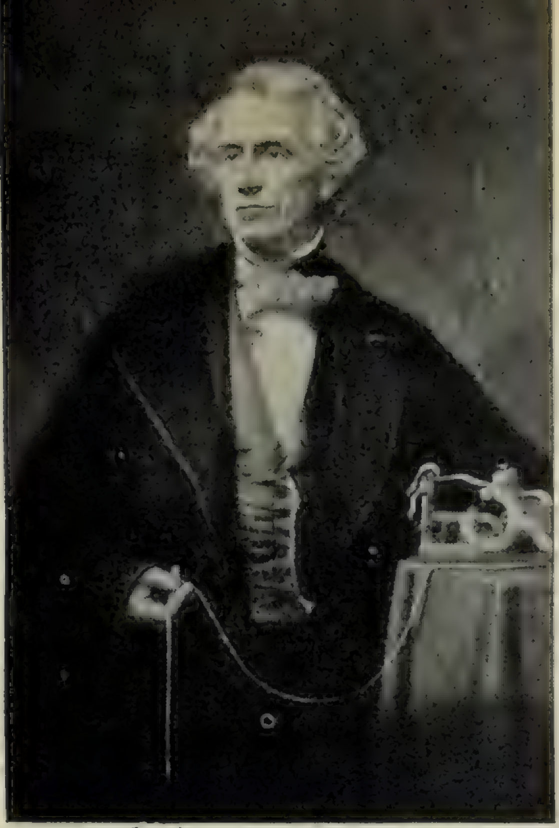

FIG. 422. Samuel F. B. Morse

FIG. 423. Alexander Graham Bell

satisfactory way of transmitting messages. As a result, on May 24, 1844, and March 10, 1876, two historic messages were sent by electricity. The first was a message by telegraph from Washington to Baltimore. Samuel F. B. Morse had proved to the world the success of telegraphic communication over a distance of forty miles. The second was a telephone message sent by Alexander Graham Bell to his assistant, Thomas Watson. About the time the telephone was invented, Heinrich Hertz, a German scientist, discovered *radio waves,* sometimes called Hertzian waves, in the space around certain kinds of electrical apparatus. Some twenty years later, in 1896, Guglielmo Marconi, an Italian, used these waves to send a message over a distance of two miles without wires. Morse, Bell, and Marconi all made use of previous discoveries, but they added new ideas which gave us three of the greatest inventions of the nineteenth century.

In 1927 the scientists of the Bell Telephone Laboratories gave a public demonstration of *television,* in which pictures of a person before the transmitting instrument in Washington appeared at the same instant in the receiving instrument in New York. Just as in the case of the other methods of transmitting messages, these men merely made an extension of the methods already in use. They used light to operate the instruments which transmitted the messages instead of sound which operates the telephone and radio. The result is a wonderful addition to our methods of communication.

If you are like most other people, you are curious about things that happen about you. Why is it often several seconds between the time you see a flash of lightning and the time you hear the thunder? Why does a vase or other object sitting on a piano often "rattle" when a certain note is played? What kinds of materials are used in insulating our buildings against sound? What causes the sound when a bugle is played? How do "sound phones" help partially deaf persons hear? How do we use the energy of electricity to transmit sound by telephone and radio? In "talking" pictures how is the talk made? By reading this unit and doing the experiments, you will be able to answer such questions for yourself and to find the answers for many more questions that will come to your mind as you watch what is going on around you in the world.

## ¶ 1. What is sound?

HOW ARE SOUNDS STARTED? The sound of one of your classmates whispering in your ear is very different from the sound of a drum. The sound of a fire siren is not at all like a heavy crash of thunder. Yet all sounds, from the faintest to the loudest, are alike in some ways.

*Experiment* 93. WHAT CAUSES SOUND? (*a*) Place a drum on the floor or on a table with one end upward. Strike the skin. Quickly put the tips of your fingers on the skin. Can you feel it vibrating? Strike the drum again and quickly sprinkle fine pieces of cork on the skin. What happens to the cork? What does this show you?

*b*) Make a rubber hammer by pushing a small wooden or iron rod into the hole of a rubber stopper. Use this hammer to strike a tuning-fork. Quickly hold the fork near your ear. Can you hear a sound? Touch your finger to one of the prongs. Does it feel the way the vibrating drum head felt? Strike the tuning-fork again. Touch the tip of one of the moving prongs to the surface of some water. What is the result?

*c*) Fasten a stiff bristle or paper triangle about one inch long to the end of one prong of a tuning-fork with a drop of wax. Smoke a piece of window-pane with a candle-flame until one side is entirely black. Lay it down with the smoked side up. Strike the tuning-fork and draw the tip of the bristle across the glass. What kind of pattern is traced? What does this show you about the tuning-fork?

In Experiment 93 you found that each of the objects that produced sound was vibrating; that is, it was moving rapidly back and forth or up and down. You could feel the drum head vibrating when you placed the tips of your fingers on it. When you sprinkled the finely ground pieces of cork upon the vibrating drum head, they began to "dance" rapidly. You could see that the drum was making them bounce. When the tuning-fork was giving out sound, you could feel the vibrations of the prongs. The prongs also spattered the water when you placed them in it. The bristle on one prong of a tuning-fork showed you that the fork was moving rapidly back and forth. From these observations you can understand that all the sounds you hear are alike in this way: They are all produced by something that is vibrating.

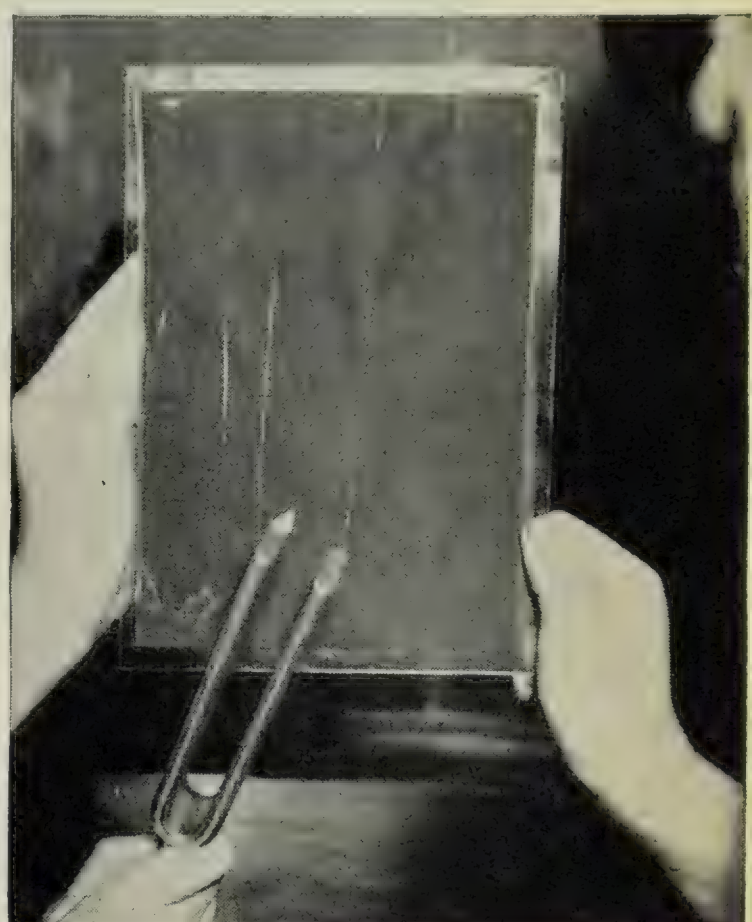

FIG. 424. Tuning-fork and plate on which the fork has recorded its vibrations

What vibrates to make the sound of your voice? Place your thumb and forefinger on your "Adam's apple" while you say a few words. As you speak, you can feel your "Adam's apple" move. Stretched across the inside of your voice-box, or larynx, are two folds of strong tissue. These folds are known as the vocal cords. It is the vocal cords that vibrate as you speak. From Figure 426 you can see that the outer edges of the vocal cords are fastened to the "frame" of the larynx. This frame is made of cartilage. The inner edges of the cords are free and can be moved closer together and farther apart by muscles. They can also be drawn tight by muscles.

To understand how the vocal cords produce sound, you can do a simple experiment. Stretch a wide rubber band rather tightly so that the two edges of it are close together. Blow between the two edges. If you do this just right, you will hear a sound pro-

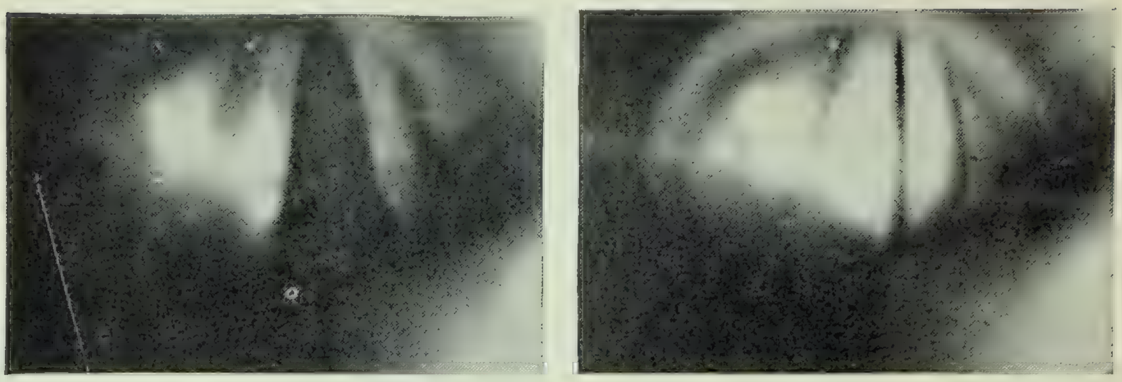

FIG. 425. These are actual photographs of the vocal cords, taken with the aid of a mirror placed in the back of the mouth cavity. At the left are shown the cords in the position they take when a person is breathing. At the right is a picture of the cords as they look when a person is speaking. (Photos by courtesy Dr. Mack D. Steer and Dr. Joseph Tiffin, Purdue University)

duced by the vibrating rubber. This is the way vocal cords work.

All the air you breathe in and out passes through your voice-box. As you breathe in, the vocal cords are drawn back, with one on each side of the voice-box. The air passes between the cords and goes on down the windpipe into the lungs. However, when you talk or sing, something else happens. Tiny nerves from your brain are connected with the small muscles that control the vocal cords. When you want to speak or sing, your brain sends messages along these nerves to the muscles. The muscles pull the vocal cords together and draw them tighter, so that there is a narrow slit between them much like the slit between the rubber bands. Then, as your chest muscles force the air out of your lungs, the air makes the vocal cords vibrate. By making the cords tighter or looser the muscles can regulate the kinds of sound.

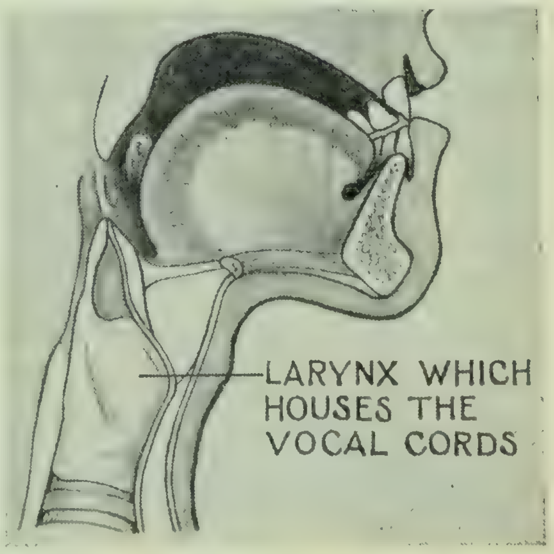


FIG. 426. The location of the vocal cords in the throat

You must not get the idea that the voice-box with its vocal cords is the only part of your body that helps you make intelligent sounds. Your lips help you speak by changing the shape of your mouth. Your

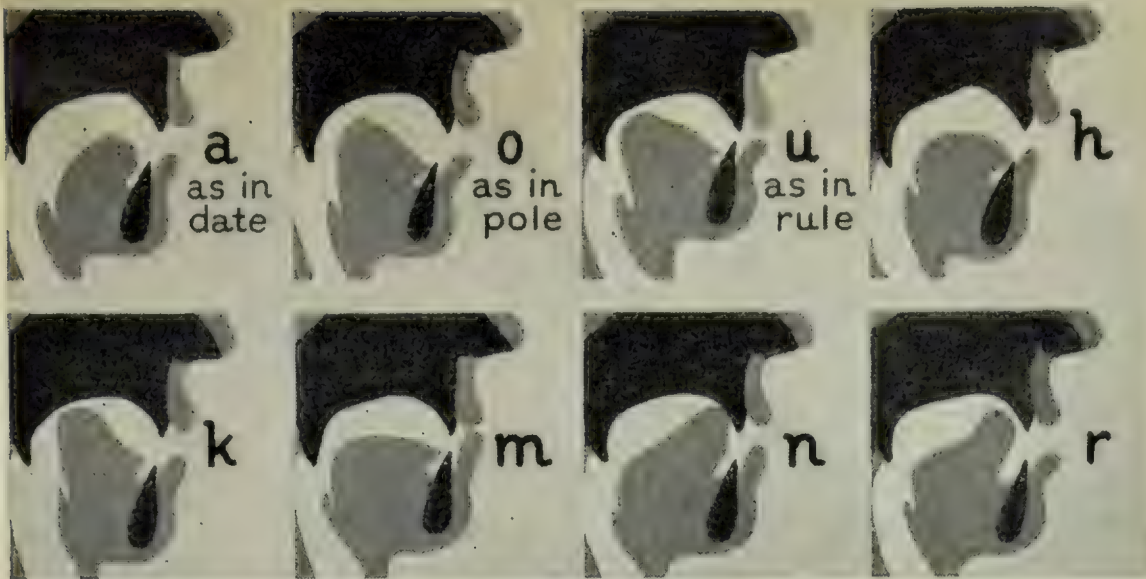


FIG. 427. Look at this drawing and then look in a mirror as you pronounce different sounds to help you understand even better how your lips, tongue, and teeth help you form sounds into words.

tongue and teeth also help in speaking. Your tongue, in particular, changes the quality of tone. The muscles of your tongue make it thick or thin and change the shape of your mouth cavity. These changes give your voice its own quality and make it possible for you to pronounce words plainly. For example, pronounce the letters *a, o, u, m, j,* and *r* plainly. Note what happens to your tongue and lips when you say these letters. Your nasal cavity helps give your voice quality, too. Repeat the letters mentioned above while you hold your nostrils shut. Do you notice how "flat" your voice sounds when your nose is closed?

*Self-Testing Exercises.* 1. Which is true? *All vibrating bodies produce sounds. All sound is produced by vibrating bodies.* Why?

2. Give examples from your own observations to illustrate what you have learned about the cause of sound.

3. Why do the vocal cords not get in the way when you inhale?

4. Begin with the air in your lungs and tell what each part of your body does in making sounds as the air moves out.

*Problems to Solve.* 1. Why is it sometimes difficult to speak after you have been running or are very excited?

2. Make up and try an experiment of your own to show that sound is produced by vibrating bodies.

WHAT CARRIES SOUND? When you are in the open, you can hear someone call you for quite a distance even though there seems to be nothing to bring the sound to your ears. When a player in the centre of a large football field shouts loudly, people sitting on all sides of the field can hear him. How does sound travel? What carries it to your ears?

FIG. 428. Apparatus to show that sound cannot travel through a vacuum

An experiment worked out by scientists helps us find out what carries sound to our ears. Study Figure 428 or, if you can, set up apparatus like it. The glass jar (called a *bell jar*) stands on the plate of a vacuum pump. The joint between the bell jar and the plate is made air-tight by means of soft wax. The alarm clock is placed under the bell on a thick pad of cotton, and is set so that it will "go off" in a minute or two. When it rings, it can be heard plainly. Then the clock is set to "go off" in five minutes, the jar is placed over it, and it is sealed up again. As much air as possible is pumped from the bell jar, and, when the clock rings, you can see it vibrating, but you cannot hear a sound!

This experiment shows that air carries sounds. When air is in the jar, you can hear the bell ringing. When there is a good vacuum between the clock and the jar, you cannot hear the alarm at all. You cannot hear it because there is almost no air to carry the vibrations that are made as the clapper strikes the gong. Now let us see whether solids and liquids can carry sounds.

*Experiment 94.* DO SOLIDS AND LIQUIDS TRANSMIT SOUND? (*a*) Put your ear against the end of a long wooden table. Have one of your classmates scratch gently on the other end of the table. Can you hear the scratching sounds? Remove your ear from the table. Can you hear the scratching sounds now? Why?

*b*) Strike a tuning-fork and hold it up in the air. Can you hear it? Cut a hole in a large cork and fit the handle of the tuning-fork into it. Set a glass of water on the top of a cigar box that lacks one end. Strike the tuning-fork and hold the cork against the surface of the water. How plainly can you hear it now?

Experiment 94 shows you that solids, such as wood and metal, transmit sound and that liquids do, also. As you would probably expect, sound travels at different speeds in different kinds of materials. In air at ordinary temperatures sound travels about 1100 feet per second. In water it travels about 4700 feet per second and in steel over 15,000 feet per second.

*Self-Testing Exercises.* 1. Tell in your own words what is shown by the experiment with the bell in a vacuum.

2. Give examples from your own experience to show that liquids, solids, and gases carry sounds.

3. About how long does it take sound to travel a mile through air? Through water? Through steel?

*Problems to Solve.* 1. Make up experiments of your own to show that solids and liquids carry sound.

2. Read in reference books about the *fathometer* and its uses.

3. If you could not see a train coming along a track, how could you hear it the farthest distance away?

4. Find out how ships can tell whether a submarine is near.

5. Find out how far away a lightning flash is during a thunderstorm. To do this, record the number of seconds between the time you see the lightning and the time you hear the thunder. Multiply this number of seconds by 1100 (the speed in feet per second of sound in air at ordinary temperatures).

6. Ask your teacher to help you find the speed of sound on your athletic field. Use a starter's pistol with blank cartridges.

WHAT ARE SOUND WAVES? Have you been wondering how a sound passes through the air? What goes from a vibrating object to your ear? Whatever it is, it must be able to pass through water and steel as well as through air.

Scientists have studied sound so carefully that they now understand very well how sounds move through materials. The results of one kind of experiment are shown in Figure 429. An electric spark, which made a cracking noise, was produced just back of the black spot in the centre of the upper picture. An instant after the first spark a second one was produced. At the same time a camera film was exposed. When the film was developed, the scientists found that the flash of light from the second spark had taken a picture of something that looked like a circle in the air.

FIG. 429. Sound waves caused by an electric spark (Photos by Dr. A. L. Foley, Indiana University)

The scientists tried their experiment again, but waited a little longer to make the second spark. The second picture they made is shown in B. When they waited still longer, the "circle" was still larger, as shown in C. Sometimes they made a whole series of sparks to start the sound. Then the picture showed just as many circles as sparks. Something moved out in all directions through the air from each spark. This "something" is a layer of the air in which the molecules of air are closely packed together. It is called a *sound wave*. When a tuning-fork is vibrating, it sends many sound waves out through the air in all directions. From a medium-sized fork the waves are about four feet apart.

However, you must not think that the molecules of air move from the tuning-fork to your ear. Each one just moves back and forth in its place, as Experiment 95 shows.

*Experiment* 95. HOW DO SOUND WAVES MOVE? Get the spring out of a window-shade roller and fasten one end of it to a support (Figure 430). Fasten a weight to the other end of the spring. Near the lower end press together several coils of the spring; then let go of them quickly. Watch what happens along the entire spring. Repeat the experiment several times. Try to explain what happens.

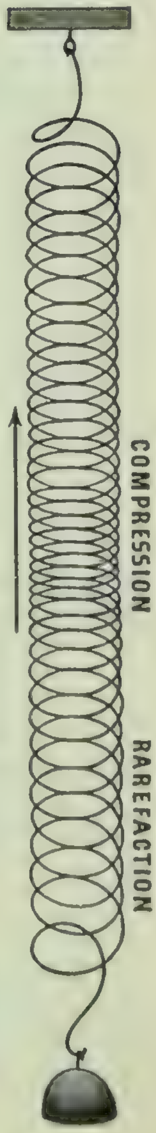

Fig. 430

The coils of the spring that you pressed together spread out and gave their motion to the coils next to them. These next coils were first pressed together and then spread out as they made other coils move in the same way. All of this happened so rapidly that a group of compressed coils seemed to move from the bottom to the top of the spring. You could see them seem to travel. Of course, the coils that you first pressed together did not move to the top of the spring. They

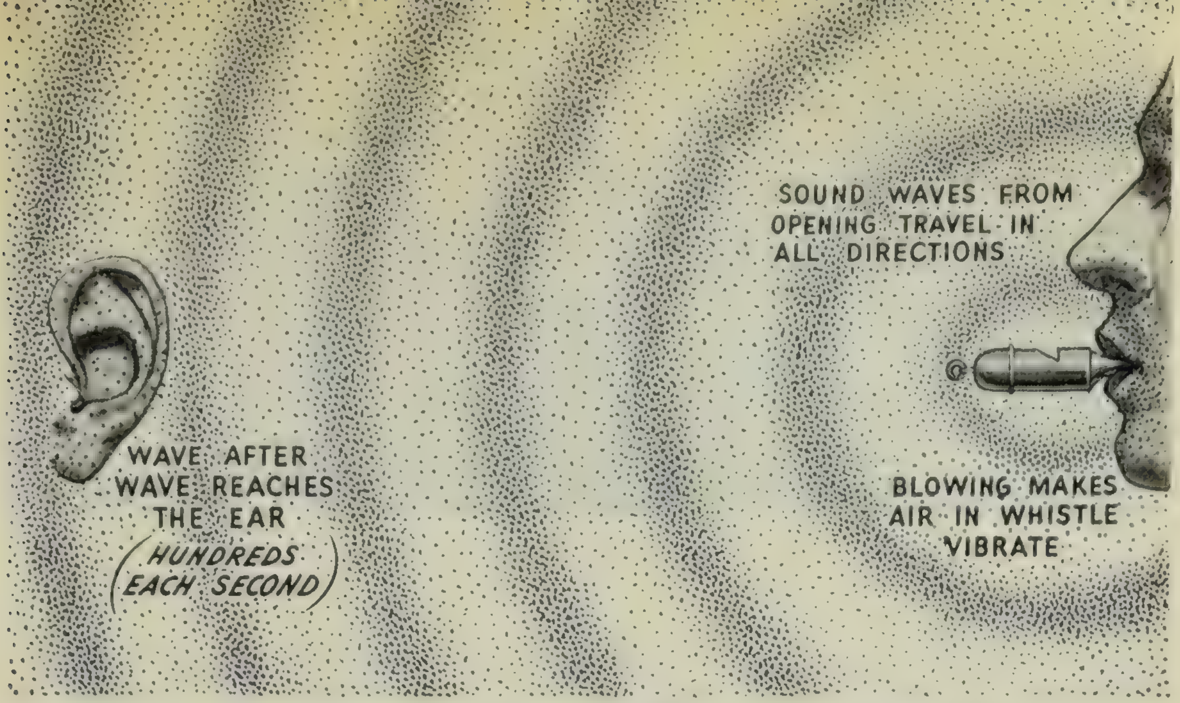


Fig. 431. How the vibrating molecules of air carry sound from a vibrating object to your ear. Notice that a complete sound wave is made up of two different bands of molecules.

stayed right where they were, near the lower end of the spring. All that they did was to spread apart far enough to press the next group of coils together. The motion of the compressed coil was what moved up the spring as it was transmitted from one coil to the other.

Now suppose that each coil of the spring is a molecule of air and that your hand is the vibrating gong of a bell. The molecules of air around the bell are first pressed together as the moving gong strikes them. These compressed molecules spread out, much as the coils of the spring spread out. When they do this, they press the next molecules close together. The second group passes their motion on to the third group, and so on until the vibrations reach the air in your ears.

The places where the air molecules are pressed together are known as *condensations* or *compressions*, and the places where they are spread farther apart are called *rarefactions* (Figure 430). A complete sound wave is made up of one rarefaction and one condensation. Study Figure 431 to help you trace a series of sound waves from their source to your ears. In a sound wave the molecules of air move only a little way. They move back and forth for a tiny distance along the line in which the sound waves are travelling. In liquids and in solids, sound waves travel in much the same way as in air. But in these substances the molecules are not so free to move as they are in air; therefore they do not move back and forth as far as the molecules of air do while a sound wave is passing through air.

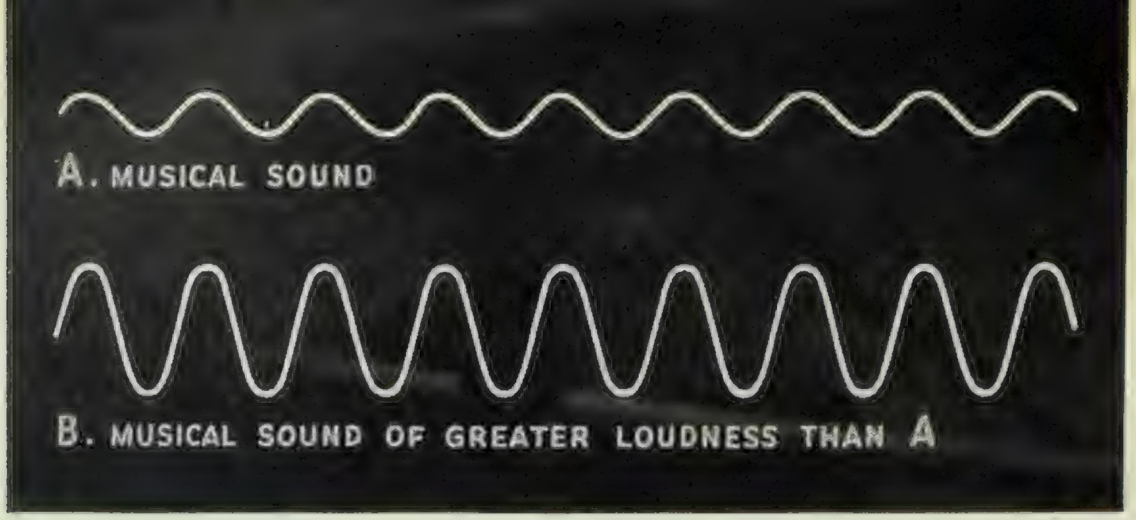


FIG. 432. A diagram of a soft sound and of a loud sound

*Self-Testing Exercises.* 1. Tell in your own words what sound waves are; then read your book again to see whether your explanation is correct.

2. How can you tell that no substance travels from a sounding body to your ears?

*Problem to Solve.* How do waves travel along a rope? Tie one end of a clothes-line rope to a tree. Stand twenty or thirty feet away and draw the rope tight enough so that it does not touch the ground. Then give it one very quick up-and-down movement. This should start a wave that travels to the tree and back. Study its behavior. Is the wave that comes back different from the wave that goes out? How is it different? Try sending two or three waves in a series.

## ¶ 2. Why do sounds differ from one another?

WHAT IS THE DIFFERENCE BETWEEN "LOUD" AND "SOFT" SOUNDS? All your life you have been hearing sounds varying from the loudest crash of thunder to the faint tick of a watch. You are so familiar with sounds that vary in loudness that you probably have not thought much about them. However, the degree of loudness is one of the important things about sound.

The loudness of a sound that you hear depends upon how far the sound waves move your ear *drum* in and out when they strike it. What makes some sound waves push your ear drum in farther than others? You learned in Problem 1 that sound waves are caused by particles of air (or other substances) that move back and forth for a tiny distance along the line in which they are travelling. Suppose you strike a drum a hard blow. The particles of air about it move back and forth for a greater distance than if you strike the drum very easily. The drum makes a loud sound. If you strike the drum an easy blow, the particles about it move

back and forth for a much shorter distance, and the sound it makes is softer.

Figure 432 shows a tracing by a tuning-fork that was making a soft sound and another by the same fork when it was making a loud sound. As you learned in Problem 1, sound waves spread out over a larger and larger area as they move away from their source. When the part of a sound wave that covered one square foot has spread until it covers two square feet when it reaches your ear, the part that strikes your ear will have only half as much energy. Therefore you will hear it with less loudness.

From what you have studied, you have learned that the loudness of sound depends upon two things: (1) how far the air molecules are moved back and forth by the vibrating body and (2) the distance you are from the source of the sound. In recent years scientists have made instruments for measuring how loud sounds are. The man in Figure 433 is using a *sound-level meter* to measure the noise of the office. This instrument measures the loudness of sound in units known as *decibels* (named after Alexander Bell, the inventor of the telephone). Continuous noise above 50 decibels in schools, homes, stores, office buildings, and

TABLE 19. INTENSITY OF ORDINARY SOUNDS*

| INTENSITY | DECIBELS | KINDS OF SOUND | INTENSITY | DECIBELS | KINDS OF SOUND |
|---|---|---|---|---|---|
| Deafening | —120—<br>—110—<br>—100— | Thunder, artillery<br>Near-by riveter<br>Elevated train<br>Boiler factory | Moderate | —60—<br>—50—<br>—40— | Noisy home<br>Average office<br>Average conversation<br>Quiet radio |
| Very loud | —100—<br>—90—<br>—80— | Loud street noise<br>Noisy factory<br>Traffic unmuffled<br>Police whistle | Faint | —40—<br>—30—<br>—20— | Quiet home or private office<br>Average auditorium<br>Quiet conversation |
| Loud | —80—<br>—70—<br>—60— | Noisy office<br>Average street noise<br>Average radio<br>Average factory | Very faint | —20—<br>—10—<br>—0— | Rustle of leaves<br>Whisper<br>Sound-proof room |

*From Bulletin VI of the Acoustical Materials Association

FIG. 433. In this picture an acoustical engineer is using a sound-level meter to measure the amount of noise in the office. (Celotex Corporation photo)

other places is believed to be harmful. This is one of the reasons why *acoustical* (sound) *engineers* try to find ways of reducing noise in the buildings where people live and work.

*Self-Testing Exercises.* 1. State in your own words why some sounds are loud and others are soft.

2. Why is it useful to measure the loudness of sounds?

3. What is a decibel?

*Problems to Solve.* 1. Sound waves become weaker because they travel outward from their source in the form of a sphere. How much weaker will a sound be at a distance of 20 feet from its source than at a distance of 10 feet? If you cannot see how to solve this problem, ask your mathematics teacher for suggestions.

2. Name three things that you can cause to give out sounds. Tell how you can make each one give out a soft sound or a loud sound.

WHAT IS THE DIFFERENCE BETWEEN "HIGH" SOUNDS AND "LOW" SOUNDS? Did your teacher ever tell your class that it was singing "off pitch"? What did he mean? Probably he sounded a "pitch-pipe" or a note on the piano to help you sing as you should. The highness or lowness of a tone is called its *pitch*. When you are singing "off pitch," you are singing a little too high or a little too low in comparison with the sound you should sing. What gives sounds their pitch? Whether the pitch is high or low depends upon the number of sound waves that are produced by a vibrating body in one second. Scientists have learned many interesting things about pitch.

*Experiment 96.* WHAT DETERMINES THE PITCH OF A STRING OF A MUSICAL INSTRUMENT? (*a*) Get some rubber bands of various lengths and thicknesses. Stretch a short band tightly and pluck it. Notice the sound it makes. Stretch a long band of the same size as tightly as you did before. Pluck it and notice the sound it makes. How does it compare with the sound made by the short band?

Select another band and hold it loosely. Pluck it and note its sound now. Stretch the band as tightly as you can without breaking it. Pluck it and note its sound. How are the sounds different?

Select a thick band and a thin band of the same lengths. Stretch them both equally tight and note the sounds they produce. Are they alike?

*b*) Ask someone in your class to bring to school a mandolin, a guitar, or a violin, or use a sound instrument called a *sonometer*, if you can get one. Pluck the smallest string and note the sound it gives. Hold the string down on the sounding-board so that the vibrating part will be shorter. Pluck it and compare its sound with that of the full-length string. Begin plucking a string and tighten it each time you pluck. How is the sound different? Pluck one of the thin strings and one of the thick strings. Compare their sounds.

c) Your teacher will remove the front of a piano so that you can see the strings. Observe their thickness and length at different places. Have someone strike different keys and watch the strings vibrate. What kinds of strings vibrate fastest?

If you are a careful observer, you learned several important things about how to make sound higher or lower. You found that a short string gives a higher pitch than a long string of the same thickness and tightness. This is true because the short string can vibrate faster. You found, also, that when you tighten a string, you make it vibrate faster and therefore raise its pitch. When you loosen it, you make it vibrate more slowly; therefore you lower its pitch. If you have ever listened to someone tune a guitar or other stringed instrument, you have heard this happen. A thick string vibrates more slowly than a thin string of the same length.

From your experiments you can see that the pitch of a sound depends upon how fast its source is vibrating. The number of vibrations per second is called the *frequency* of a sound. The frequency of a vibrating string depends on: (1) the length of

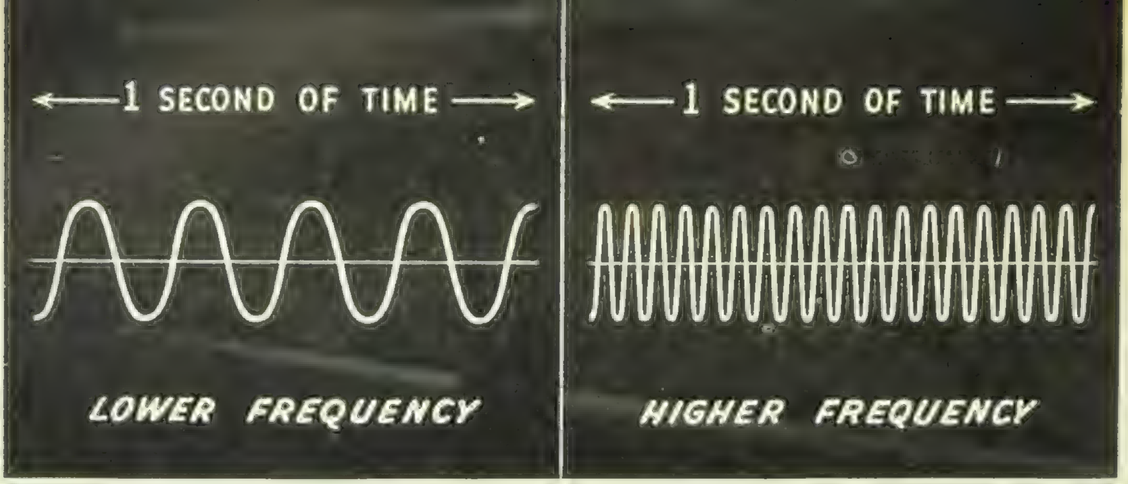


FIG. 434. This diagram will help you understand what is meant by the pitch of a sound.

the string, (2) the tightness of the string, and (3) the weight of the string. People who play or manufacture musical instruments use the principles that you have learned to produce the proper kinds of sounds. For example, people who make pianos must know what kinds of strings to use, and a piano-tuner must know how tight to make the strings. Scientists have learned that the key called Middle C on a piano must vibrate 256 times per second if the piano is in tune according to a scale known as *Standard Pitch*. The lowest organ note has a frequency of 16 vibrations per second. The frequency of the highest piano note is 3500 vibrations per second.

*Self-Testing Exercises.* 1. Tell what is meant by the pitch of sound. What happens when the pitch of a sound is changed?

2. Without looking at your book show by means of rubber bands of different sizes that you know what determines the pitch of a vibrating string.

*Problems to Solve.* 1. To help you understand pitch better, learn how a player tunes some stringed instrument, such as a violin or a guitar.

2. If a sound can travel 1100 feet per second, how far apart are the waves from a tuning-fork or string at middle C?

3. The highest note on a full-sized piano has a frequency of 3500 vibrations per second. How long are its sound waves at ordinary temperatures?

4. Find out from some reference book how a rise in temperature of the air affects the length and speed of sound waves.

5. What are the "beats" that are heard when two musical sounds are at very nearly the same pitch? What causes them? Physics books will help you find the answer.

6. Examine a bicycle siren and try to explain why it changes its pitch as you ride at different speeds.

## 3. How do we hear?

WHAT ARE SYMPATHETIC VIBRATIONS? In Problem 1 you learned how sounds are sent out by our voices. Have you ever wondered how we hear these sounds? Scientists are not yet sure how our ears work, but they learned some important things. To understand the facts about your ears, you should know something about *sympathetic vibrations*. Perhaps you have noticed that when someone is playing a piano, a vase or other light object on the piano may rattle. Did you ever hear someone say that if you held a large sea-shell to your ear, you could hear the roaring of the sea? Of course you did not hear the roaring of the sea, but you did hear faint roaring noises. What causes the vase to vibrate, and why does the sea-shell sound when you hold it to your ear? Before you try to answer these questions, do the following experiment to see if you can produce sounds in a similar manner.

*Experiment* 97. HOW CAN ONE SOUNDING BODY PRODUCE SOUND IN ANOTHER BODY? (*a*) Get two cigar boxes that are the same size and remove one end from each box. Close the tops and fasten them with tiny nails. Place the boxes about six inches apart, with their open ends facing each other. Get two tuning-forks that are alike (that produce the same number of vibrations per second—256 for example). Have a classmate hold the base of one of the forks against the top of one of the cigar boxes.

Strike the other tuning-fork and hold it against the top of the other cigar box. Then stop the tuning-fork from vibrating by closing your fingers about the prongs. Listen carefully to the tuning-fork that your classmate is holding. How do you explain the results?

*b*) Repeat the experiment, using two tuning-forks that do not give the same number of vibrations per second (for example, forks whose vibrations are 256 and 320). Listen to the tuning-fork that is not struck. Does it sound?

In part *a* of the experiment the tuning-fork you struck sent out vibrations into the air. As the vibrating particles of the first sound wave reached the still fork, they made it move back and forth a little in response to their motion. The second wave gave the fork a little push just as it started on its second vibration. Each sound wave thus made the second fork vibrate a little more. The second fork then gave out sound because it was tuned to the

first fork; that is, it could give out the same number of vibrations per second as the first fork, and the rate of its vibrations was the same as the rate at which the sound waves struck it.

In part *b* of the experiment the still fork did not sound in response to the fork you struck. The still fork could not vibrate in time with the waves that struck it. In other words, the still fork was "out of tune" with the fork you struck. As a result, it gave out no sound. Do you see that sound waves make a body vibrate if the body can give out the same number of vibrations per second as the sound waves that reach it? When sound waves from one body make another body vibrate, the two objects are said to be in sympathetic vibration.

Sympathetic vibrations occur very often, but most of us pay little attention to them. Hold down the loud pedal of a piano and sing a loud "O" sound. You will hear sympathetic vibrations from the string of the piano that is in tune with the note you sang. Watch the radio when it is playing loudly. Some small glass or metal object on the radio may vibrate in response to certain sounds. Scientists tell us that sometimes very fragile glass vases have been broken by means of sympathetic vibrations. Can you now tell why the sea-shell mentioned on page 593 gives out a faint roaring noise when you hold it tightly against your ear?

*Self-Testing Exercises.* 1. Explain in your own words what causes sympathetic vibrations.

2. Give examples of your own to illustrate what is meant by sympathetic vibrations.

WHAT IS THE STRUCTURE OF THE EAR? Three things are necessary for us to hear a sound. First, as you know, vibrations must be produced by some rapidly moving object. Second, some material must carry the sound waves from the vibrating object to us. Third, there must be something to receive these vibrations and interpret them as sounds. Our ears and brains are the parts of our bodies that do this. Figure 435 shows that an ear consists of three parts—the *outer ear*, the *middle ear*, and the *inner ear*. The outer ear is made up of the shell of flexible cartilage and skin that is attached to each side of the head. It includes also the opening, or *canal*, that leads into the head. A thin membrane, the ear

*drum*, is stretched across the inner end of the canal. The drum is the partition between the outer ear and the middle ear.

In the middle ear are three tiny bones fastened together by ligaments. The first of the bones touches the drum. The third bone is in contact with the inner ear. The inner ear consists of a device, the *cochlea*, which is shaped like a snail's shell and is filled with a liquid. The cochlea has a spiral membrane that is fastened to the central part, much as the threads are coiled about a screw. This membrane is made of a great many crosswise strands of varying lengths. The *auditory* (hearing) *nerve* leads out from the cross strands to carry the impulses to the brain.

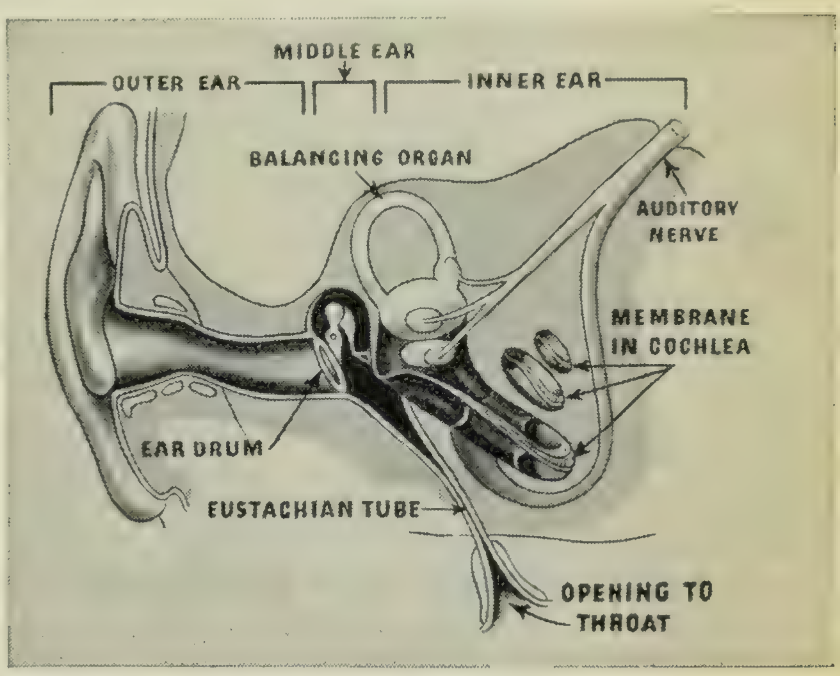

FIG. 435. The parts of the ear

HOW DOES THE EAR WORK? Now that we know how the ear is made, let us follow a sound wave to see how each of the parts of the ear helps us hear. The outside part of the ear is really a "megaphone in reverse"; that is, it collects sound waves and leads them into the canal. Get a megaphone and hold the mouthpiece to your ear. You will be surprised at the results, for even in a room so still that you can "hear a pin fall," you can hear many noises. Sounds too faint and scattered to be noticed can be heard easily with a megaphone in this position. Now you understand why people who are partly deaf used to have ear trumpets. However, as you will learn later, another kind of device is now used by people who are hard of hearing.

As sound waves reach the middle ear, the back-and-forth movements of the air particles cause the drum to move back and forth (see page 587). The vibrating drum makes the three tiny bones vibrate, and these bones carry the vibrations to the liquid of the cochlea. You learned earlier in this part of the unit that a vibrating body can cause another body to vibrate in sympathy with itself if the two bodies are in tune (Experiment 97).

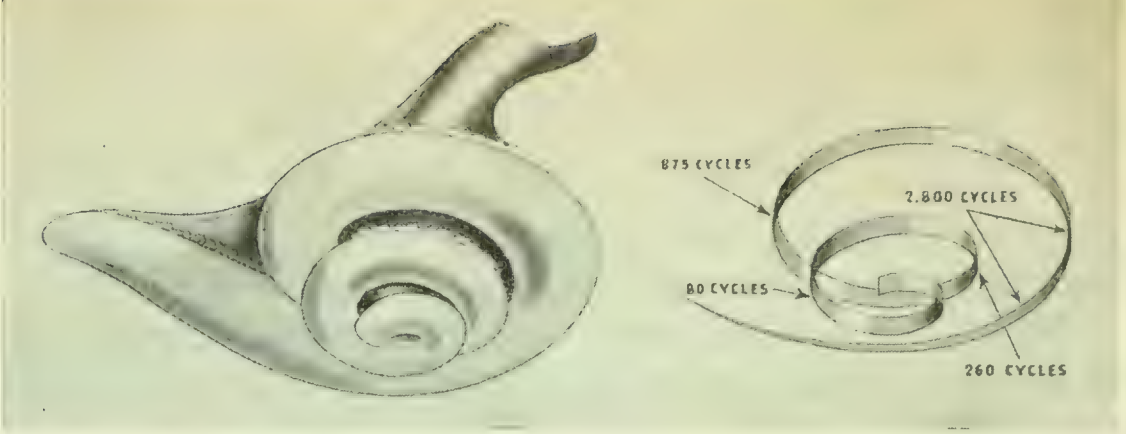


FIG. 436. At the left is a drawing of the outside of the cochlea. At the right is shown the membrane that enables us to tell high sounds from low sounds. The numbers show the parts of the membrane that vibrate in response to sounds of those frequencies. *Cycles* mean the number of vibrations per second.

One theory of how we hear is that the vibrations of the liquid in the inner ear cause sympathetic vibrations in the spiral membrane of the cochlea. For example, the long strands respond to low-pitched sounds, and the short strands respond to high-pitched sounds (Figure 436). Tiny nerve fibres are connected all along the spiral membrane. The part of the membrane that is vibrating sends nerve messages to the brain. Thus we can tell the kind of sound we are hearing. In this way we can hear sounds that range from 16 vibrations per second to 20,000 per second. Think how delicate these hearing organs must be. The tiniest bit of energy is changed into air vibrations by someone's vocal cords, by a ticking clock, by a falling spoon. These vibrations spread out in all directions until only a thousandth or a millionth part of the energy reaches our ears. Yet we recognize the sound and can usually tell which direction it came from.

Figure 435 shows a peculiar part known as the *balancing organ*. This organ does just what its name tells us; it helps us keep our balance. Probably when you ride rapidly on a merry-go-round, you feel dizzy. This is because the liquid in this balancing organ is disturbed.

Did you ever ride very swiftly up several stories in an elevator or up a steep mountain road? Probably you felt a peculiar sensation in your ears. You heard a slight popping noise, and the pressure in your ears felt too great. Someone may have told you to swallow several times to relieve this. What really happened was that the air-pressure very rapidly became less on the outside of your ear drums. This left the pressure much greater on the inside of your ear drums. When you swallowed, some air moved out

through your *Eustachian tube* (Figure 435) to let the pressure become the same on the two sides of your ear drums.

People who are "hard of hearing" no longer need to use ear trumpets. Modern hearing aids have a "microphone," "radio set," and a "loud-speaker," or receiver. One kind is so fixed that the receiver can be placed in the opening of the outer ear to strengthen, or *amplify*, the vibrations that are received. Another kind is made so that the receiver is clamped just back of the ear. The vibrations that are received by this instrument are transmitted through the bones of the head to the liquid of the inner ear.

You will understand better how the last-named instrument works if you will stop both ears tightly and hold a watch between your teeth. You can hear the watch quite plainly. Its vibrations are transmitted through your teeth to the bones of your head and then to the liquid of the inner ear. There the auditory nerve carries the impulses to the brain, where they are registered as sound.

Since it is very important for us to hear well, let us mention a few ways of caring for the delicate organs with which we hear. A thick waxy substance is secreted in the canals to protect them. This wax should never be removed with a small sharp stick or other sharp instrument. You should be careful not to swim in water that might have germs in it, since some of them might easily get into the canals of your ears and cause infections. Before you do much diving, you should have a doctor examine your ears to see that they are in good condition, as sudden changes of pressure affect the drums. The doctor may advise you to wear rubber "ear stoppers" for protection. You should avoid letting anyone shout loudly in your ears. The sudden vibrations might push the drums in too far and injure them. Also avoid "blowing your nose" too hard when you have a cold. The pressure may push bacteria up the Eustachian tube into the middle ear. Remember to consult a doctor when anything is wrong with your ears.

*Self-Testing Exercises.* 1. Compare the crosswise strands of the spiral membrane of the cochlea to the strings of a piano. How are they alike? How are they different?

2. Why do you think it was necessary for you to learn about sympathetic vibrations before you could learn how we hear?

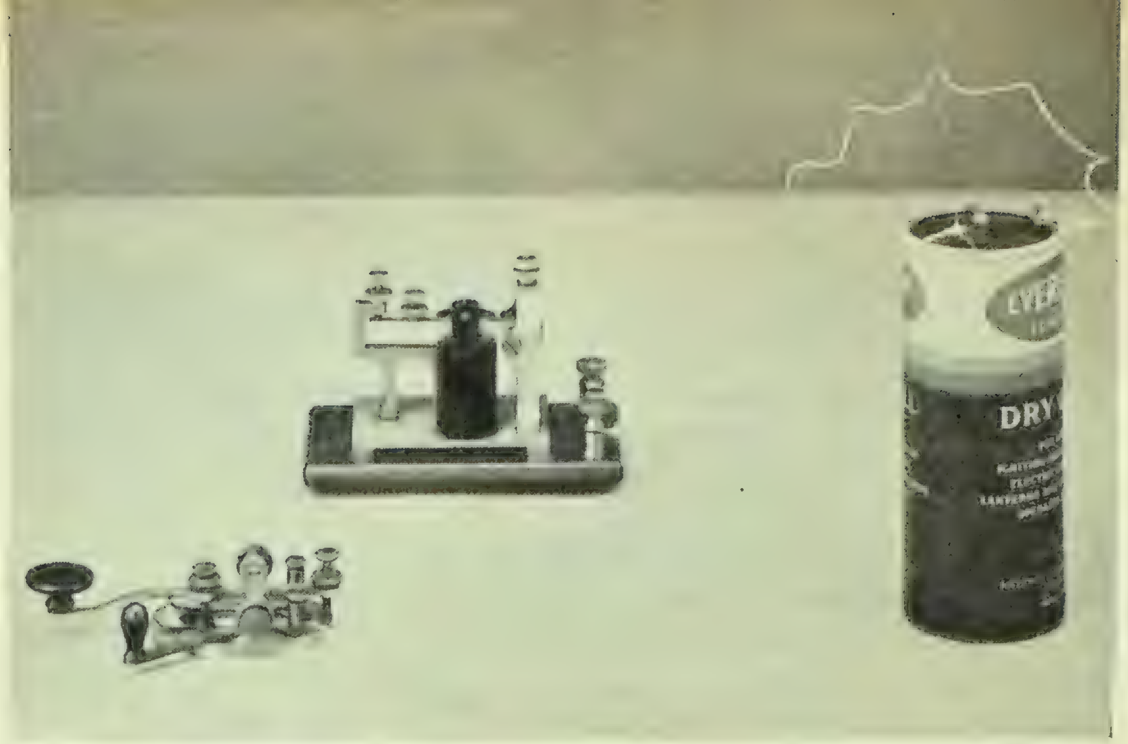


FIG. 437. Sending key, sounder, and battery of a simple telegraph set

3. Tell what happens in hearing sounds from the time the sound waves reach your ears until the brain "registers" the sound.

4. What is the Eustachian tube for?

5. List the ways by which you can take care of your hearing.

*Problems to Solve.* 1. Find out how your school doctor tests your hearing when he gives you a physical examination.

2. Look in some good reference book to learn more about how the balancing organs work.

## 4. How is the energy of electrical current used for sending messages?

HOW ARE MESSAGES SENT BY TELEGRAPH? To discover how electrical energy is used for sending messages, first make a simple telegraph outfit to see how it operates. Then you can more easily understand why it works as it does.

*Experiment 98.* HOW IS A SIMPLE TELEGRAPH INSTRUMENT SET UP AND OPERATED? (*a*) Connect a cell, a *sending key*, and a *sounder* as in Figure 437, using two wires to complete the circuit. Open the switch on the key. Press down on the key. What happens? Release the key. What happens?

(*b*) Press down on the key and release it immediately. You hear two clicks close together. This is called a *dot*. Press down on the key, hold it an instant, and then release it. You now hear two clicks not so close together as when you made a dot. This is called a *dash*. The difference between a dot and a dash is the difference in time between the two clicks, and these dots and dashes make up the tele-

FIG. 438. A home-made telegraph. At the right is the key. The sounder clicks between the nail and the top of the electromagnet, which is a nail wound with wire.

graphic code. Try sending a series of dots and dashes until you can tell them apart.

c) If you do not have a commercial key and sounder, make an instrument as shown in Figure 438. Use about fifty turns of wire on the nail.

The two round spool-like parts in the sounder are the two arms of a horseshoe-shaped electromagnet. The little bar (armature) that goes across the poles of this electromagnet is made of soft iron. This cross-bar is attached to a heavier steel bar that can move up and down. A spring holds the steel bar so that the end stays up against a small screw in the frame. When the key is pressed down, the circuit is completed. The electrical current flows from the cell around through the coils of the magnet through the key and back to the cell. When this happens, the electromagnets pull down the armature, and a click is heard. When the key is released, the circuit is broken. Then the electromagnets lose their magnetism, the spring pulls the armature up, and another click is heard as it strikes the upper screw. When the key is pressed down again, the same events take place again.

A telegraph circuit thus contains a source of electricity, a device to make and break the circuit (the key), and a device that uses an electric current to make sounds (the sounder). Simple instruments of this kind are still widely used in railroad communication and for lines where few messages are sent. In many cases

only one wire is used with these instruments; the ground takes the place of the other wire in the circuit. For commercial telegraphy, where thousands of messages may be sent over a line in a day, many complicated devices have been invented to speed up the sending and receiving of messages. For example, messages may be sent by striking keys like those on a typewriter. At one or many receiving stations, machines called *teletypewriters* receive the electrical impulses from the receiving instrument and automatically type out the letters of the message on a sheet of paper or on a paper tape. A single circuit can be arranged to carry messages from four or more sending instruments at the same time.

*Self-Testing Exercises.* 1. Explain how a telegraph sounder produces sounds.

2. Why is a key necessary in a simple telegraph circuit?

3. What is a teletypewriter?

HOW DOES A TELEPHONE WORK? When you talk over the telephone to a person a few miles or even thousands of miles away, you can hear the person as well as if he were standing near you. He speaks in his usual way, and so do you. Neither of you shouts, but still you can hear one another. Ordinary sound waves, as you know, could not travel this distance and be heard. Furthermore, you hear the person as he speaks. It would take several seconds for the voice of a person ten miles away to reach you through a wire. You see, therefore, that it is not sound, as many people think, that is sent through the telephone wire.

We will suppose now that you are talking over a telephone. What happens? Sound waves are set up in the air as you speak. These sound waves enter the mouthpiece of the *transmitter* (Figure 439). Inside the transmitter is a thin piece of metal, the *diaphragm*. When the sound waves strike the diaphragm, they make it vibrate backward and forward. For example, if the sound wave vibrates 256 times per second, the transmitter diaphragm will vibrate at the same rate. Attached to the back of the diaphragm is a little box containing carbon particles through which the current must pass. As the diaphragm moves in, these carbon particles are pressed closer together (A of Figure 440), and their resistance to the passage of an electrical current is decreased.

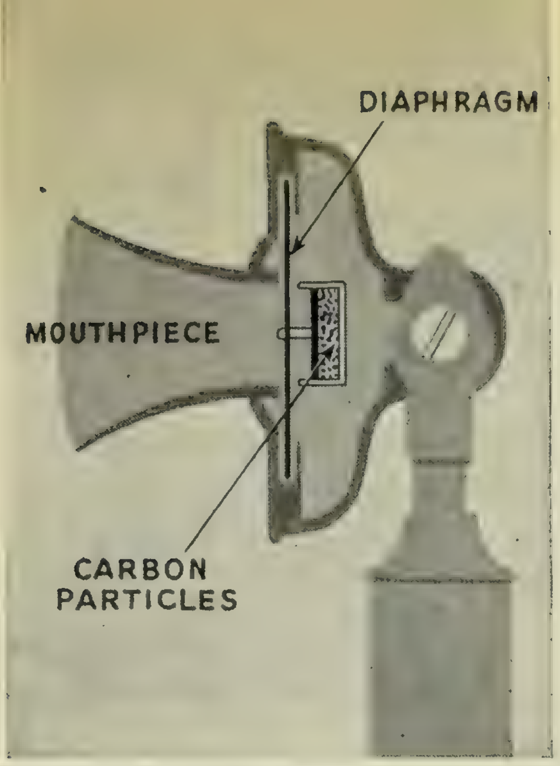


Fig. 439. How the transmitter of a telephone is constructed

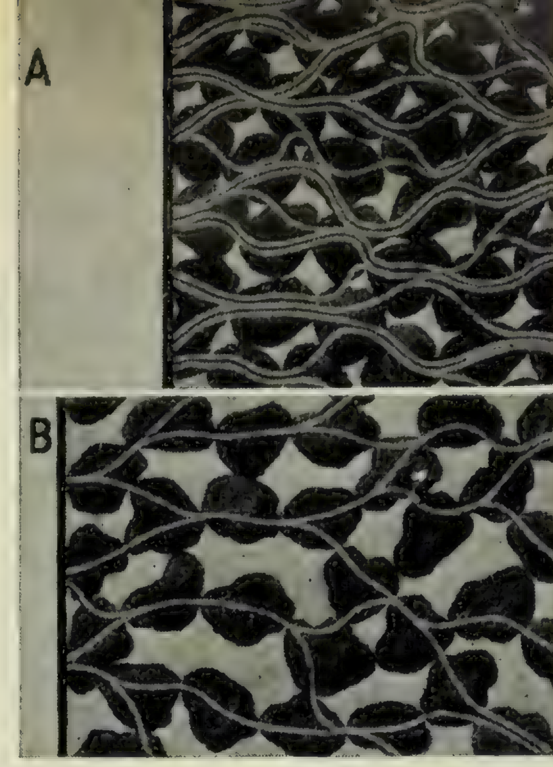


Fig. 440. Carbon particles in a telephone transmitter

Some source of electrical current, such as a dry cell, is connected in series with the box of carbon particles. As you already know, when the resistance is decreased, more current can flow. So every time the diaphragm goes in, the strength of the current is increased. When the diaphragm moves back out again, the resistance is increased; therefore less current flows through the carbon. The strength of the current therefore increases, then decreases, then increases, and so forth. For this reason the electric current that flows through the transmitter and out into the wire going to the *receiver* changes from a strong current to a weak current, then back to a strong current, and so on. It makes these changes the same number of times per second that the sound wave strikes the transmitter. Such a current may be called a *pulsating current*, or a *fluctuating current.*

At the receiver end of the circuit it is necessary to change this pulsating current of electricity back to sound waves so that you can hear. This is done in the receiver of the telephone. If you unscrew the cover of a telephone receiver, you will first see a metal diaphragm (Figure 441). When the diaphragm is removed, you see two electromagnets wound with many turns of wire. These electromagnets receive the pulsating current from the transmitter. What happens then?

When the current gets stronger, the electromagnets become stronger, and they pull the centre of the diaphragm inward. When the current gets weaker, the pull on the diaphragm is released,

and it flies back to its original position. The diaphragm, therefore, moves inward and outward at the same rate at which the current changes its strength. As it does this, it sets up sound waves in the air. These sound waves travel to your ear, and you hear. The diaphragm in the receiver vibrates at the same rate as the sound wave that struck the diaphragm in the transmitter. Therefore you hear the voice that set up the sound wave.

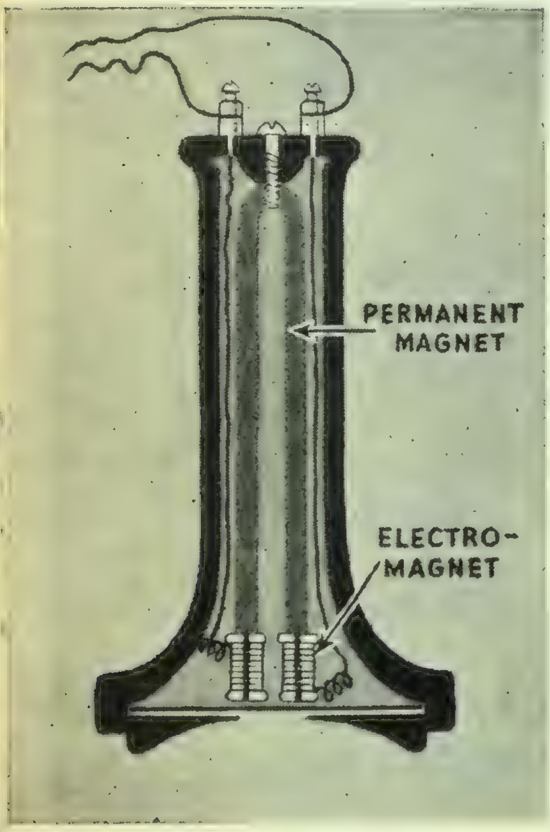


FIG. 441. A telephone receiver

Of course, few telephones are as simple as the one you have just been reading about. Near each instrument there is usually a bell and devices for ringing the bell to call someone to talk on the phone. If there are many phones in the system, an *exchange* is necessary. In the exchange a person called an *operator* answers your call, calls the person you want, and connects your phone with the other phone. Many other devices in the exchange turn signal lights on and off, give "busy" signals, and help in other ways to give good telephone service. In some exchanges the connections between telephone instruments are made by machines instead of by human operators. These machines are much too complicated to explain here.

*Self-Testing Exercises.* 1. What passes along a telephone wire to carry the message from you to a friend?

2. Explain carefully what happens in the telephone transmitter while you are talking.

3. Explain carefully what happens in the telephone receiver at your friend's ear while you are talking.

4. Diagram the simplest telephone circuit you can imagine.

*Problems to Solve.* 1. Try to make a telegraph circuit that will work by using the ground in place of one wire. Push a spike nail or iron rod into moist soil at each instrument. Connect one wire from each instrument to the spike or rod and have the second wire run all the way between the instruments.

2. Plan a telegraph circuit that will include two sounders and two keys so that messages can be sent in either direction.

3. Read in reference books about Samuel F. B. Morse and his invention of the telegraph.

4. Find out what a *telegraph relay* is and how it works.

5. Learn the telegraph code of dots and dashes well enough to spell out your name.

6. Obtain a telephone transmitter, receiver, and dry cell. Connect them so that the sound of tapping on the transmitter can be heard in the receiver. Demonstrate the circuit and operation to the class.

7. Visit the nearest telephone exchange and ask to be shown as much as possible of its operation.

8. Read in reference books about Alexander Graham Bell.

9. Learn all you can about automatic telephone exchanges and how they work.

HOW DOES A RADIO WORK? In the telephone you have seen how sound waves can be used to change the strength of an electric current, how the pulsating electric current is used to change the strength of an electromagnet in a telephone receiver, and finally how this magnet operates the diaphragm to produce sound waves again. This is practically the same process that must take place in transmission by radio. The big problem in radio is to transmit electrical energy without the use of wires. Let us first see how electrical energy travels through air or empty space without the use of wires. You already know that sound and light are transmitted by waves. It should be no surprise to you to learn that there are also electromagnetic waves. These waves, like light, travel through a vacuum at a speed of 186,000 miles a second.

In the broadcasting station is an apparatus that generates a very rapidly alternating current. This generator causes electrons to flow back and forth in the *aerial* (wires or tower) that sends out the radio messages. For example, if a station is operating on a *frequency* of 600 *kilocycles*, the current is rushing up and then down the aerial 600,000 times per second. As the current rushes up and down the aerial, it sets up electromagnetic waves that travel out from the aerial. Six hundred thousand waves per second are sent out at the rate of 186,000 miles per second. Each station must have a very complicated set of radio tubes, coils, and other devices to send out waves at just the correct frequency.

To listen to a certain station, you know that it is necessary to

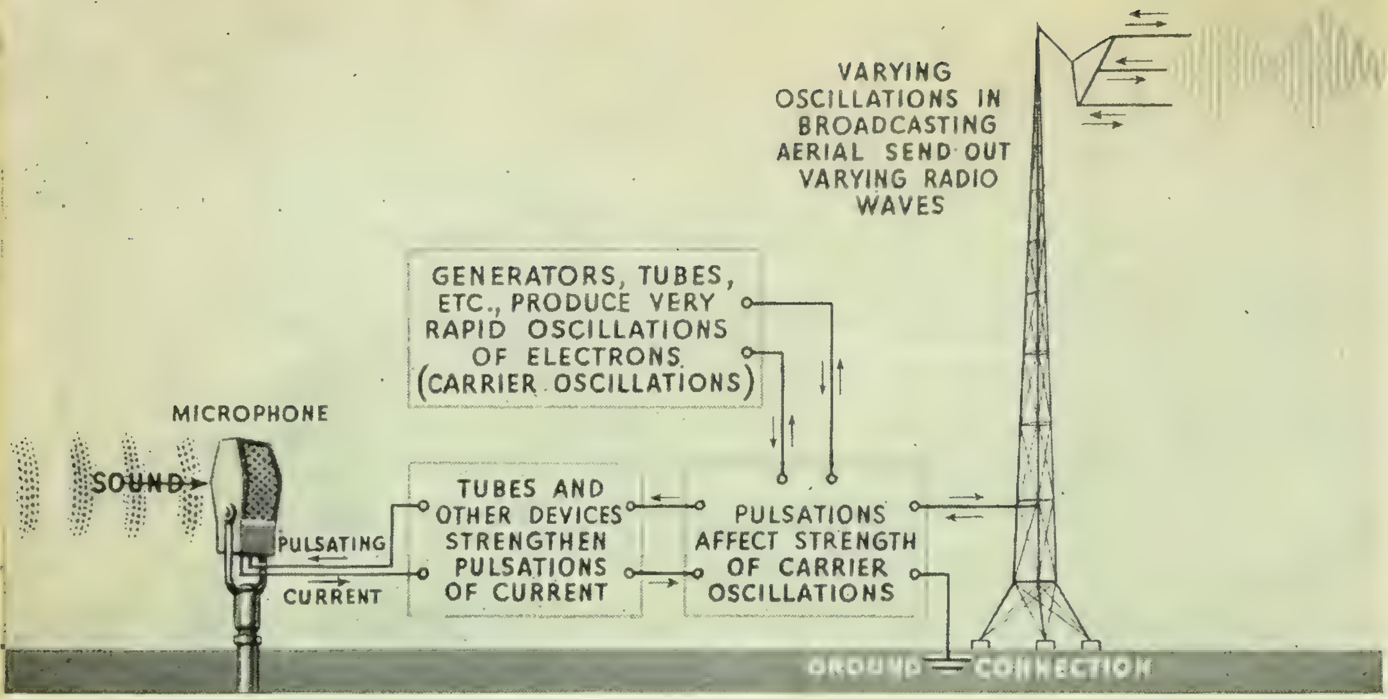


FIG. 442. A simple diagram of a radio sending station

tune your set to the frequency upon which the station is operating. Now let us see why this is necessary. When you studied sound, you learned about sympathetic vibrations (pages 593-594). You found out that a sound wave of a certain frequency could make another body vibrate and produce sound if the frequency of the sound wave was the same as the frequency at which the body would vibrate. By tightening or loosening a violin string, a musician can tune the string until it will vibrate in sympathy with a string on a second violin. A somewhat similar thing happens in radio. The electrons in the aerial of a radio set will respond to a certain frequency of electromagnetic waves. By the use of coils and other devices in the set, it is possible to change the frequency to which the aerial and the receiving instrument will respond. In other words, tuning a set means changing it so that it will respond sympathetically to the frequency of the station you want.

Now let us come back to the broadcasting station. The singer or speaker sings or talks into a microphone. This microphone is really nothing but a very sensitive transmitter, such as is used in the telephone. The sound waves striking the microphone cause a pulsating electrical current in the wires connected to it just as they do in the telephone transmitter. By very complicated arrangements in the sending station, the pulsating microphone current changes the strength of the radio waves that are being sent out from the aerial. These changes correspond to the sound waves that strike the microphone. Figure 442 shows you what happens to sounds after they enter a microphone.

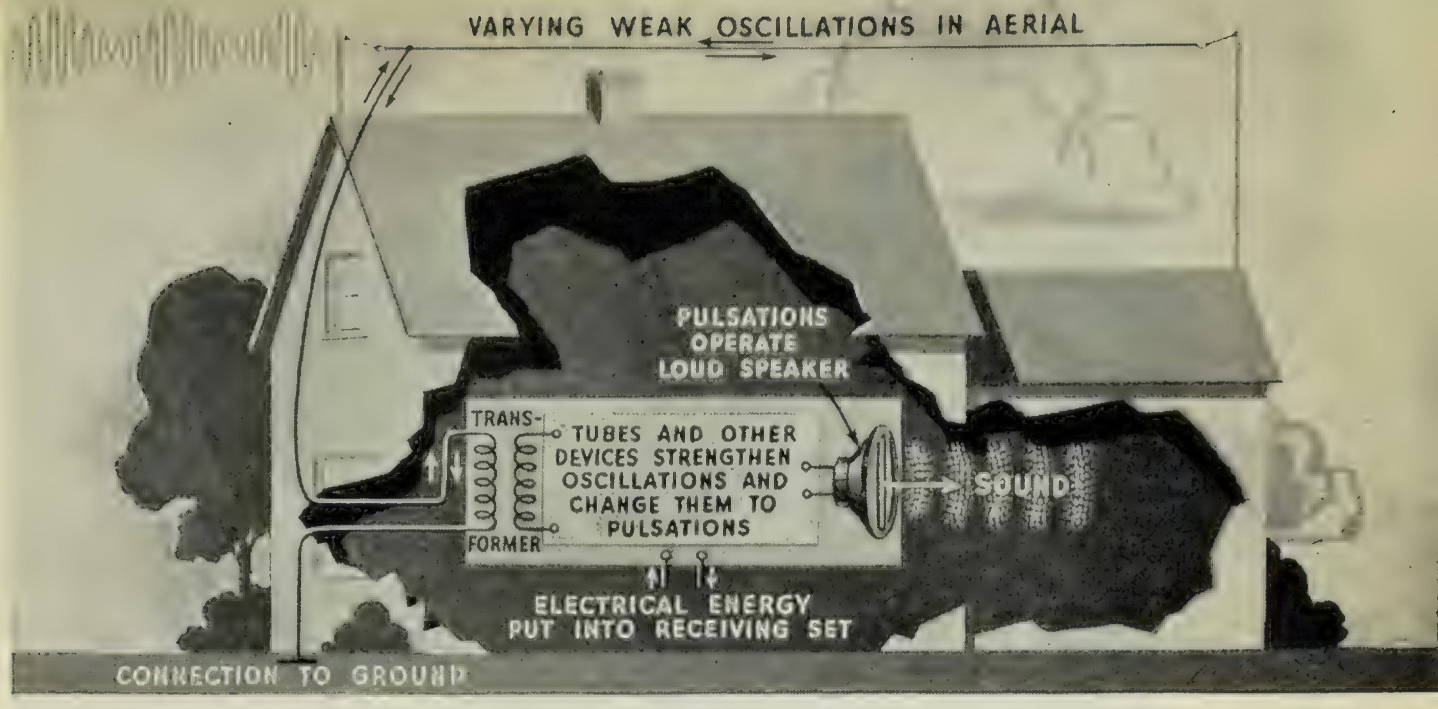


FIG. 443. A simple diagram of radio receiving station

Now we have the electromagnetic waves, or *radio waves* as they are called, going out into space. These radio waves strike the aerial of your receiving set that is tuned to respond to those particular waves. The electrons in the aerial and the set begin to rush up and down your aerial at the same frequency as they are rushing up and down the aerial of the sending station. Of course, this alternating current in your set is much weaker than in the sending station. To strengthen it your receiver must be connected to a source of electrical energy (Figure 443).

First, the feeble but very high-frequency alternating current is amplified, or strengthened, by the radio tubes in your set. Of course, the electrical energy supplied to the set helps do this. Next, the alternating current is sent to a special tube called a *detector*. In this tube the high-frequency alternating current is changed to a pulsating direct current. This direct current pulsates in the same way as the current in the microphone. This current is again amplified by being sent through transformers and tubes until it is powerful enough to operate the electromagnet in the loud-speaker. Then the diaphragm in the loud-speaker sends out sound waves that you hear.

HOW DOES TELEVISION WORK? Unless you have attended one of the World's Fairs or have been at a radio show, you have probably never seen a television set work. In a television set a picture of what is happening in the broadcasting station is sent to you by radio. You see the singer as you listen to him. In this respect, it is like the talking pictures in the movies.

Fig. 444. A television receiver. The picture produced by the receiver is reflected from a mirror in the cover. (R. C. A. Laboratory photo)

Television differs from ordinary radio in two important ways: First, light waves (instead of sound waves) must be used to change the strength of the current sent out by the aerial. Second, the electromagnetic waves that can be used in television are very much shorter waves than those in the radio. They travel in straight lines, and the distance at which they can operate receiving sets is very limited. Only a few large cities have television broadcasts, and these can be received for only a few miles.

In this elementary textbook you can get only a few general ideas of how television operates. At the sending-station the scene to be sent (*televised*) is illuminated with a strong light. The objects in the scene reflect light to a camera-like piece of apparatus. The dark parts of the objects reflect less light than the light parts. The amount of light reflected from various parts of the object sets up a pulsating current in the camera-like apparatus. This pulsating current controls the strength of the high-frequency waves sent out by the aerial of the sending station. At the receiving end the pulsating current produced operates a special kind of tube which forms a luminous picture of the object televised.

*Self-Testing Exercises.* 1. How are radio waves produced?

2. What is meant by "tuning" a receiving set? Why must it be in tune with the sending station?

3. What effect do the electrical pulsations in a radio microphone circuit have on the waves that leave the sending aerial?

4. Why does a receiving radio set need to be connected to a source of electric current?

5. State one use of radio tubes.

6. What is television?

*Problems to Solve.* 1. How many differences can you find between radio waves and sound waves?

2. How does a vacuum tube of a radio work? Find what you can about these tubes in reference books.

3. How are electrical *condensers* used in radio sets?

4. Examine the working parts of a radio set and learn what changes are made while the set is being tuned.

## Looking Back at Unit 17

1. Copy the headings of all the problems and sub-problems of the unit. Under each one write the main ideas that are needed to give a good answer to that problem.

2. Show that you know the meanings of the following words by using them in sentences or in other ways:

| | | |
|---|---|---|
| *auditory nerve* | *decibel* | *pulsating current* |
| *cochlea* | *television* | *sound waves* |
| *condensations* | *pitch* | *sympathetic vibration* |
| *rarefactions* | *radio wave* | *vocal cords* |
| *frequency* | *amplify* | *kilocycle* |

## Additional Exercises

1. When you are sitting at the back of a large auditorium, you hear the low notes and the high notes of an orchestra at the same time. Do you think that pitch affects the speed of sound? Explain.

2. Speaking-tubes are long tubes with funnel-shaped ends. Voices can be heard long distances through walls by using such tubes. Explain why they are successful.

3. Make a string telephone. To do this, fasten the end of a long, strong string or a small wire tightly in the bottom of a medium or large-sized tin can. In the same way fasten the other end in the bottom of another tin can. Stretch the string or wire tight and speak into one tin can while a friend holds the other can to his ear. Does sound travel along the string or wire?

4. Read about Hermann von Helmholtz and some of the things he discovered about sound.

5. How are sounds used to study the structure of rocks below

the surface of the earth? This is called *geophysical prospecting*. Look in reference books under this name and in articles on petroleum.

6. Find out about the "Doppler effect." First hear it for yourself. Stand by a road while automobiles are passing. Notice whether the pitch of the sounds they make becomes higher or lower as they go by you. Then look in physics books to find the cause for the change in pitch.

7. Can a telephone transmitter be used as a receiver? Can a receiver be used as a transmitter? Explain.

8. Two wires are used in city telephone systems, while in many cases only one wire is used for country lines. Why is this so?

9. Learn the meaning of the different symbols used in the radio diagrams to be found in scientific magazines and radio manuals.

10. Secure a worn-out radio tube. Carefully break away the metal or glass and examine the parts. Prepare an exhibit for your class.

11. Investigate the "telephoto" process of telegraphing pictures that is now in common use in securing news pictures.

12. How does modern communication help transportation systems?

## Books to Read

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MANY CENTURIES AGO THE ARABS were among the most learned people in the world. They made many discoveries in chemistry, physics, medicine, astronomy, and geography. In this picture some Arabian thinkers are wondering why the rod looks bent at the point where it enters the water. Do you know why? In this unit you will learn that the appearance of the rod is caused by the way the light acts, and you will learn many other things about light. (Bausch and Lomb photo)

# UNIT 18

# How Do We Use the Energy of Light?

## Looking Ahead to Unit 18

While this book was being written, a very interesting invention was made to help avoid automobile accidents on hills. The invention looked like a bridge across the highway at the top of the hill and about twenty-five or thirty feet above the pavement. But the purpose of this structure was to act as a support for huge sheets of glass. As you started up the hill, you looked up into the glass, and you could see any automobiles that might be on the other side of the hill.

Perhaps you think that this was made possible by mirrors, but you are mistaken. The glass into which you looked was clear glass. You were looking through it, and you were actually seeing over the top of the hill and down the other side. Do you have any idea how this sheet of glass could make it possible for you to see in a way that you know you cannot ordinarily see? What did the glass do to show you the road on the other side of the hill? You will be able to explain this interesting invention when you have found out in this unit how light acts.

If you have a ruler on your desk, look at it. You will see that it looks perfectly straight. But there is a way to make the ruler look as if it were bent. Just hold it in a slanting position in water and look at it from the side. Of course, putting the ruler in water does not bend it. It just looks as if it were bent. But why does it look this way? If you hold the ruler straight up in the water and look down at the end in the water, you will see that it looks much shorter. Why do you suppose it looks bent when held in a slanting position and shorter when held upright?

Did you ever wish that you had eyes in the back of your head, so that you could see what was going on behind you? Perhaps you think that your teacher has. There is, of course, no way to

FIG. 445. This new traffic safety invention has been designed to allow a driver to see over a hill. Do you know how it works to show drivers whether any vehicles are coming up the other side of the hill? (Photo by Mieth from *Life*)

look behind you without turning your head. But there is a way to see behind you. If you have not guessed already what that way is, you will understand when we say that all you need is a mirror. You probably look at yourself in a mirror at least once a day. If you are a girl, you may look more often. A mirror is such a common thing that you have probably never wondered why you could see yourself in it. But why can you? You cannot see yourself if you face a piece of wood or a piece of paper. Perhaps you think the answer is that you can see yourself in the mirror because it is shiny. But why can you see yourself in shiny surfaces and not in other kinds of surfaces?

These questions are only a few of those that can be asked about the way in which light behaves. You can see already that people who say, "I believe what I see," had better be careful. What they think they see is often much different from the real facts. It is an actual fact that a short girl will look shorter and fatter if she wears a dress with stripes running around the body or with a large plaid pattern. She will look taller and slimmer in a dress with vertical stripes. It is also a fact, as you know, that a magnifying-glass will make objects look larger, and a telescope will make distant objects appear much nearer. Colors of objects do not always appear the same, either. In the sunlight they do not look the same as they do in the light of an electric lamp.

In this unit we will try to find out the reasons for some of the strange ways you see things. When you know how light travels and how it behaves under certain conditions, you will be able to understand the experiments and the facts about which you have just read.

## ¶ 1. How does light behave?

WHY ARE OBJECTS VISIBLE? When you go into a totally dark room, what do you see? Nothing, of course. Then you turn on a switch, and presto, your invisible surroundings become visible chairs, tables, rugs, and pictures. They were there all the time, but you could not see them. Just a turn of a switch that lighted a small electric lamp brought about this change. The lamp, however, has the power of sending out light. When it sends out light, it becomes visible itself. And its light helps you see other things that do not themselves give out light. Curiously enough, certain people of long ago thought that they could see things because something travelled from their eyes to the object. We now know, however, that we see because light travels from the object to our eyes.

While it is true that we can see only objects that send light to our eyes, there are very few objects that have the power of producing and sending out light. The sun, as you know, is one of these. From far out in space, other suns, the stars, send us their dim light. Metals give off light if they are heated hot enough. In our electric lamps a fine wire is heated so hot that it gives out light. When materials burn, the materials in the flame are heated and become *luminous*; that is, they give out light.

An object must send light to our eyes before we can see it. You can understand, therefore, that objects which do not produce and send out light of their own must be lighted by some source of light. If we are to see an object, light from the luminous source must be *reflected* from the object to our eyes.

WHAT HAPPENS TO LIGHT WHEN IT STRIKES MATERIALS? You have already learned one thing that can happen to light when it strikes a material. It can be reflected. Whenever you look through a window-pane, you are making use of another way that light behaves when it strikes a material. It passes right

FIG. 446. One of the most modern developments in lighting is the use of translucent blocks of glass for walls or for large areas in walls. In this way the interiors of buildings receive a softer and more even light, in addition to getting more light.

through the glass to your eyes, and you can see things outdoors almost as well as if the glass were not there. We say that a material such as glass is *transparent.* Air and cellophane are two other transparent materials. Hold a sheet of paper between your eyes and a window or an electric lamp. Can you see through the paper? Does any light come through? Materials that are like the paper are said to be *translucent.* Some light passes through a translucent material, but not in such a way that we can see objects clearly on the other side. Frosted glass, oiled paper, parchment, and thin silk are all translucent materials.

But light cannot pass through some materials. If you hold a sheet of iron or copper between yourself and a light, no light at all comes through. The metals are *opaque.* Whether a material is opaque or not depends somewhat on its thickness. If you hold one sheet of writing-paper up to the window, it appears translucent; but if you use a dozen sheets, the paper will be opaque. Perhaps you are wondering what happens to the light that strikes an opaque material. If you look on the lighted side of an opaque object, you can see it. This shows that light is being reflected. But few materials can reflect all the light that strikes them.

*Experiment 99.* WHAT BECOMES OF LIGHT THAT IS NOT REFLECTED FROM AN OPAQUE MATERIAL? (a) Use a perfectly dark room for this experiment. Arrange a lamp with an opaque shade so that almost all the light shines downward in a small space on a table or on the

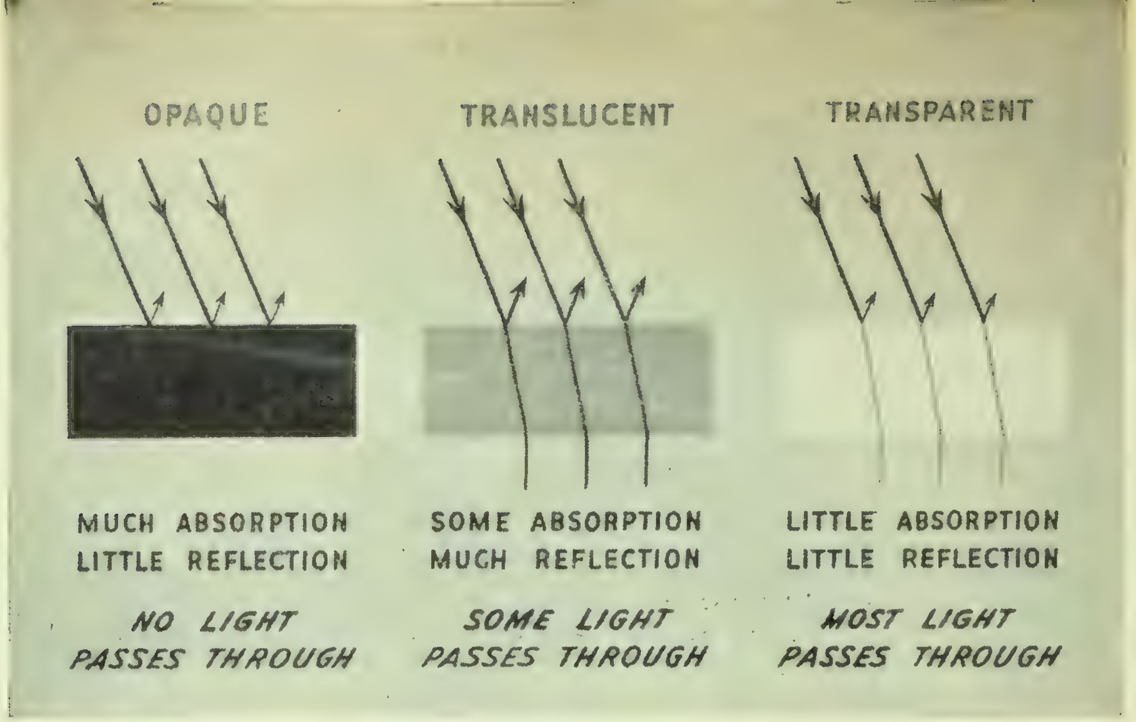


FIG. 447. Be sure that you can explain this diagram.

floor. Lay a sheet of paper or a white cloth in the light from the lamp. Notice how well you can see things in the room.

*b*) Now lay a very dark or black cloth in place of the white material. What difference does this material make in the amount of light in the room? Can you explain the difference?

The same amount of light leaves the lamp in the first part of the experiment as in the second. Yet there is a great difference in how light the room is in the two cases. Much of the light disappears when it strikes the dark cloth. We say that it is *absorbed*. In general, dark materials absorb much light, and light-colored materials reflect much of it. You have now learned that when light strikes a material, several different things may happen. It may be reflected, it may disappear (be absorbed), or it may be transmitted through the material. If it is transmitted so that we can see through the material, we say that the material is transparent; if not, we say that it is translucent.

*Self-Testing Exercises.* 1. Why can you see nothing in a totally dark room?

2. Is it correct to say that anything which can be seen is luminous? Explain your answer.

3. Explain why the book that you are now reading can be seen.

4. State three things that may happen to light when it strikes a material. Use the three words at the top of Figure 447.

*Problems to Solve.* 1. You can see an object held on the opposite side of a glass of clear water, but you cannot see the object if the water is muddy. Explain.

FIG. 448. Notice how differently the light is reflected from the materials in this room. For example, the boy's white shirt reflects much light, but his trousers reflect little light. In the ceiling is a light covered with a sheet of frosted glass. (General Electric Co. photo)

2. Explain why you are not able to see objects clearly in a fog.
3. Is the moon luminous? Explain.
4. Is light a form of energy? Explain your answer.

HOW DOES LIGHT TRAVEL? When you put a ringing bell under a bell jar and pump out the air, the sound of the bell becomes fainter and fainter. If you make an almost perfect vacuum, you cannot hear the bell at all. As you learned in Unit 17, this happens because sound must have some material through which to travel. Is this true of light? When the bell in the vacuum can scarcely be heard, you can see it just as well as at first. Light shines right through the vacuum to the bell and is reflected back to your eyes. That is, light can travel through a space where there is no material at all. You know that this is true, because you can see the sun, moon, and stars. There are thousands and even millions of miles of empty space between us and these heavenly bodies that are visible to us.

Just how light is able to travel through a vacuum has never been learned. We must, therefore, just accept the fact that it does. However, scientists have been able to learn a number of facts about how light travels. How fast do you think light travels? This is one thing scientists have been able to find out quite accurately. And, believe it or not, light travels at the rate of more than 186,000 miles per second! Think of this speed! Light could

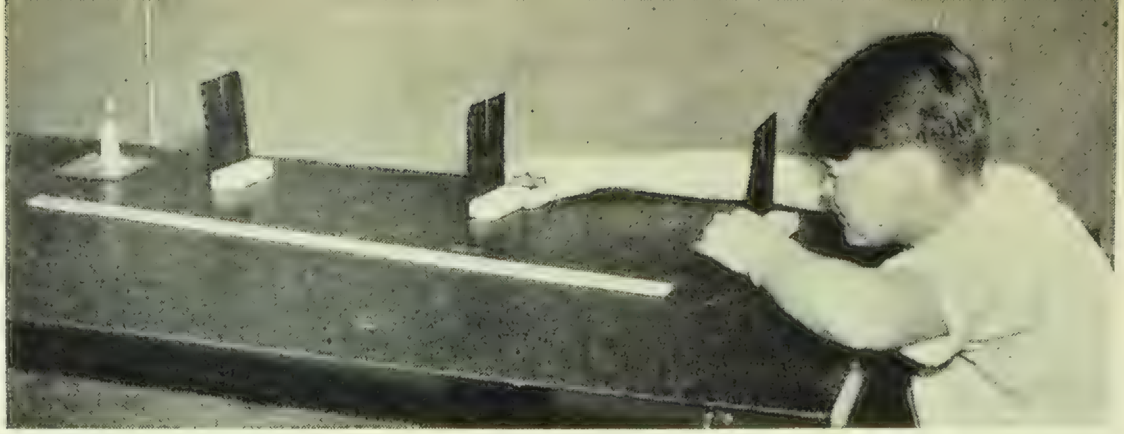

FIG. 449. Apparatus for Experiment 100

travel around the earth more than seven times in one second. This great speed accounts for the fact that we can see something happen when it happens. Suppose that an automobile upsets at a distance of 100 feet from you. How long will it take light to travel from the car to you? You could figure this out, but to save your time, we will tell you. It takes about 1/10,000,000 (one-ten-millionth) of one second. For all practical purposes, therefore, you see something happening while it is happening.

Another fact about how light travels explains why we cannot see around a corner. You know that you can hear around a corner, but you cannot see around a corner unless the light is reflected by a mirror. Why is this true? An experiment will help you see the reason for this fact.

*Experiment 100.* IN WHAT WAY DOES LIGHT TRAVEL AWAY FROM AN OBJECT? Obtain three pieces of cardboard, tin, or wood about six inches square. Cut a narrow slit in the centre of each, as shown in Figure 449, and arrange some way of supporting each piece in an upright position at a distance of about one foot from each other. For a source of light use a candle, an electric lamp, or a flashlight.

Now look through the slits and move the cards until you can see the light. Then take a straight metre stick or yard stick and place it along the top of the slits. You will find that the slits are all in one straight line. If one card is moved out of line just a fraction of an inch, you will no longer be able to see the light.

Your experiment showed that when light travels through air, it moves in straight lines. We call these lines *rays* of light. Now let us see how this explains why we cannot see objects around the corner of a building. A luminous object sends out light in all directions. The rays (lines) of light cannot pass through the opaque building; so these rays will not reach your eyes. The ray of light that passes the corner of the building goes straight out

and does not reach your eyes if you are "around the corner." You cannot see an object unless you are in the path of a ray of light that comes from the object. When you are in a dark room, you can see light from the outside because some of the light is reflected to your eyes. If the man in Figure 450 wants to see the car, what must he do?

*Self-Testing Exercises.* 1. Give a good reason for believing that light can travel through an empty space (a vacuum).

2. Explain why you can see the steam from a train whistle before you can hear the sound.

3. How does Experiment 100 show you why you cannot see around a corner?

*Problems to Solve.* 1. The sun is approximately 93,000,000 miles away. If for some reason the sun should suddenly disappear, how long would it be before we would know it?

2. If an observer located on the North Star had a telescope powerful enough to see what is happening on the earth, he would not see the start of the Great War (August, 1914) until February, 1969. How could you use these dates to discover how far away the North Star is?

3. Suppose you have a flashlight and are in a dark room. You want to cast the shadow of a book on the wall. How would you do it? How would you make the shadow smaller or larger? Make some diagrams to show the correctness of your answer.

FIG. 450

4. How does the formation of a shadow show that light travels in straight lines?

5. Make a ball of clay about one-half inch in diameter. Assume that this ball is a very highly magnified point of light in a luminous object. Stick toothpicks in the ball to show how light would be sent out by this point of light.

6. You have probably been told to have the light come from the left side when you are writing. Why is this a good practice?

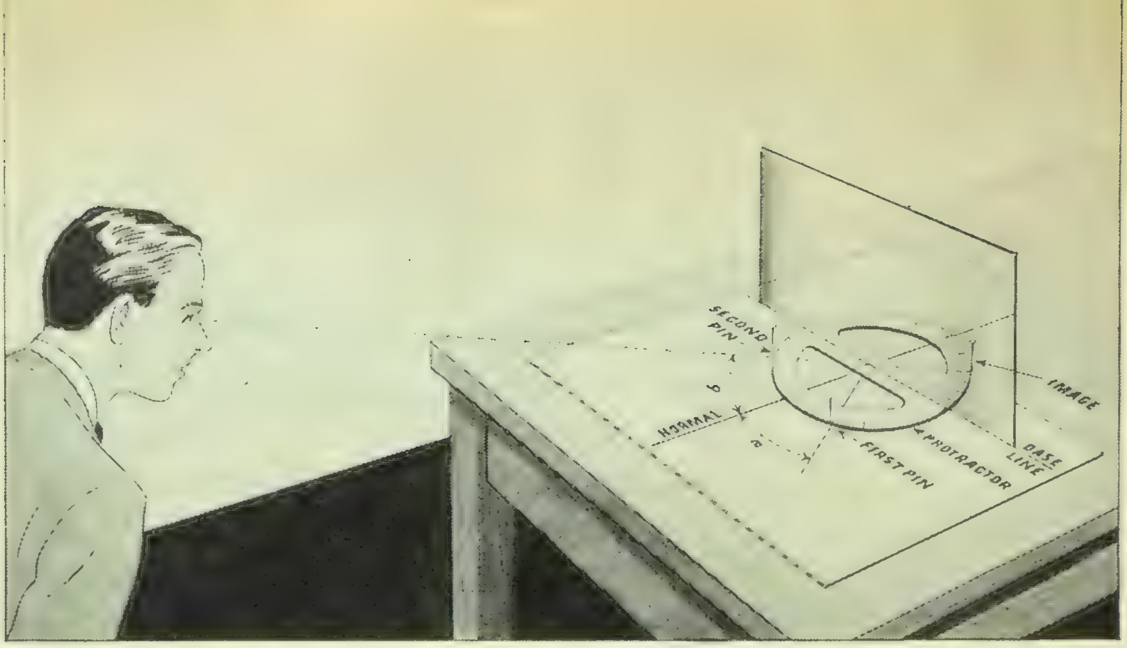


FIG. 451. Apparatus for Experiment 101

## ❰2. How do we use reflected light?

HOW IS LIGHT REFLECTED? Did you ever notice that when you stand directly in front of a mirror, you can see yourself, but that when you stand a little to one side of the mirror, you see objects on the other side of the room? To explain this, you must understand how light is reflected. A ray of light that strikes a mirror perpendicularly to its surface is reflected straight back from the mirror. What happens is similar to what takes place when you bounce a tennis ball off a wall. If you throw the ball so that it strikes the wall at an angle, it will bounce away from the wall at an angle. Light is reflected in the same way.

*Experiment* 101. HOW IS LIGHT REFLECTED? (*a*) Draw a line across the middle of a piece of paper and stand a mirror on this line, called the *base line*. Use a metal mirror if possible. Stick a pin in the paper a few inches in front of and to the right of the middle of the mirror. Close one eye and move your head until your open eye is level with the top of the table and is in front of the left side of the mirror. Look at the image of the pin, and place a mark on the base line at the point where you see the image in the mirror. Stick a pin a few inches in front of the mirror on the line along which you are sighting.

Remove the mirror and draw a line from each pin to the point that you made on the base line. These lines form two angles (*a* and *b*) with a perpendicular (*normal*) to the base line at the same point. How do these angles compare in size? (If you know how to use a protractor, measure the degrees in the angles and compare them.)

*b*) Repeat part *a*, with the first pin in a different position.

The light from the first pin goes to the mirror and is reflected to the eye. The angle between the ray of light that strikes the

mirror and the normal (perpendicular) to the mirror at that point is called the *angle of incidence* (angle *a*, Figure 451). The angle between the reflected ray and the normal is called the *angle of reflection* (angle *b*). From the experiment, how does the angle of incidence compare in size with the angle of reflection? What would happen to a ray of light that struck the mirror or any reflecting surface perpendicularly? You understand now why you can see objects on the other side of the room, and even around a corner, when you look slantingly into a mirror.

Of course you know that only smooth, flat, and highly polished metals or pieces of glass coated with silver will reflect light in the way shown by your experiment. When a whole beam of light is reflected together, as sunlight is reflected from a mirror, we say that the light is *regularly reflected* (Figure 452). Any surface that reflects light regularly acts as a mirror. Light is also reflected from unpolished materials but not the same as from a mirror.

*Experiment 102.* HOW IS LIGHT REFLECTED FROM UNPOLISHED SURFACES? Cover a table with a dark-colored cloth (dull black is best). Arrange a lamp under an opaque box or reflector so that it shines only on a small area of the table. Now place a large piece of white cardboard, a white cloth, or a piece of white paper in the lighted space beneath the lamp. Move the paper around and look at the ceiling. Does it light the ceiling? Does it light a large or a small space? Now place a mirror beneath the light. How does the reflection from the mirror differ from the reflection from the white paper?

When reflected light is scattered, as with the white paper, we say that it is *diffused*. The paper diffuses the light, because it is not quite smooth. It may look smooth, but even the smoothest-looking paper has a surface of tiny hills and valleys. When light strikes such a surface, it is scattered in all directions (Figure 453).

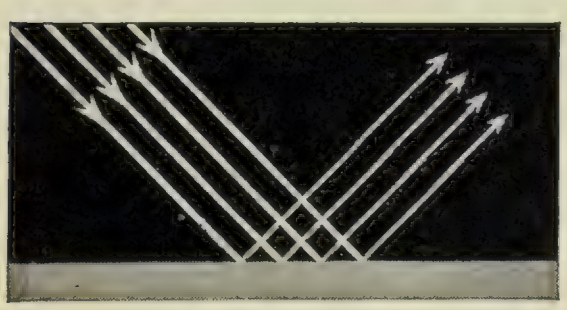

FIG. 452. Regularly reflected rays

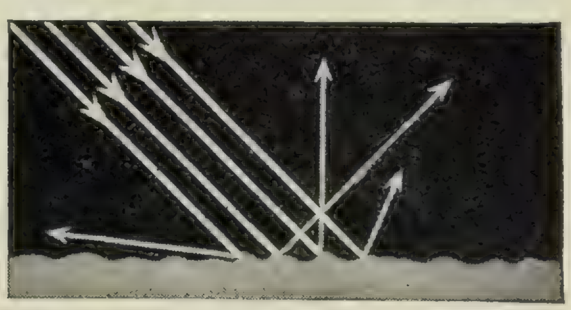

FIG. 453. Diffused rays of light

Fig. 454. An almost perfect reflection in the quiet water. (© Fox Photos, Ltd.)

Fig. 455. The movement of the water changes the image of the trunk of the tree.

You can see the difference between regularly reflected light and diffused reflected light by looking at the reflection of trees in a pool of water. Or you can pour some water into a dish and place one or two objects near it, so that you can see the reflection in the water. When the water surface is perfectly still, the picture in the water is a clear-cut reflection of the trees or objects (Figure 454). When the water is disturbed by waves, the reflection is irregular, and the objects do not appear as a true picture.

In using the reflection of light you must remember what you learned in Experiment 99. Materials differ a great deal in their reflecting power. Bright objects or light colors reflect a great deal of light. This is why they appear bright to you. Dark-colored objects or dull objects absorb light and reflect very little. Experiments have shown that white walls reflect about 80 per cent of the light that falls on them; medium gray reflects about 35 per cent; dark brown, 15 per cent; dark green, 5 per cent; and black, practically none.

*Self-Testing Exercises.* 1. Make a drawing of a mirror with a candle at one side of the mirror. Then draw an eye to show where you would have to be to see the candle in the mirror. Explain how you determine just where to place the "eye."

2. How do you account for the difference between light reflected from a mirror and light reflected from a piece of white paper? (Refer to Experiment 102.)

3. Why do some objects appear dark while others appear light or bright?

FIG. 456. Figure 458 on the next page will show you how some of these people can see over the heads of the other people by using the mirrors in periscopes. (Fox Photos, Ltd.)

*Problems to Solve.* 1. Explain why a wet pavement or a wet spot on a pavement shines.

2. If the paper of a book is very glossy, it is hard on the eyes while reading. Explain.

3. Why are dark-colored roads harder to see at night than white-colored roads?

4. Why does it not get dark immediately when the sun sinks below the horizon?

5. Which would be lighter: a winter night when the ground was snow-covered or a summer night? Why?

6. Why are white or yellow strips often painted down the middle of paved highways?

HOW DO WE USE MIRRORS? You have been looking at mirrors all your life. But have you ever studied a mirror? For example, when you look in a mirror, does the right side of your body appear on the right side of the image in the mirror or on the left side of the image? To answer this question you must remember that your image is facing you. If you put your finger over your right eye, it will appear over the left eye in your image. We say, therefore, that images in a mirror are reversed. If this is true, how would a word written on a piece of paper appear if held up and read in the mirror? Try it and see. Were you right? Another strange thing about a mirror is that you can see yourself walking toward or away from a mirror. Did you know this? Try it. When you stand in front of a mirror, you will see that your image appears as far back in the mirror as you are in front of it. Experiment 103, on the next page, shows how you can prove this.

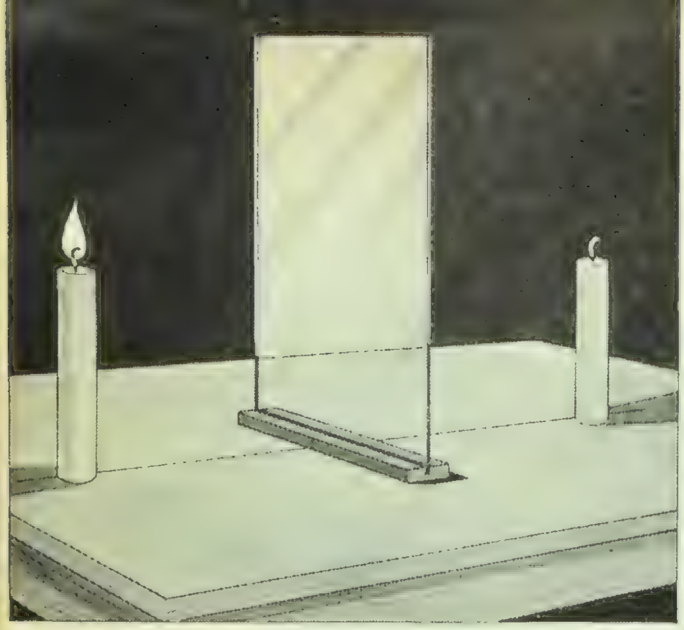

Fig. 457. Experiment 103

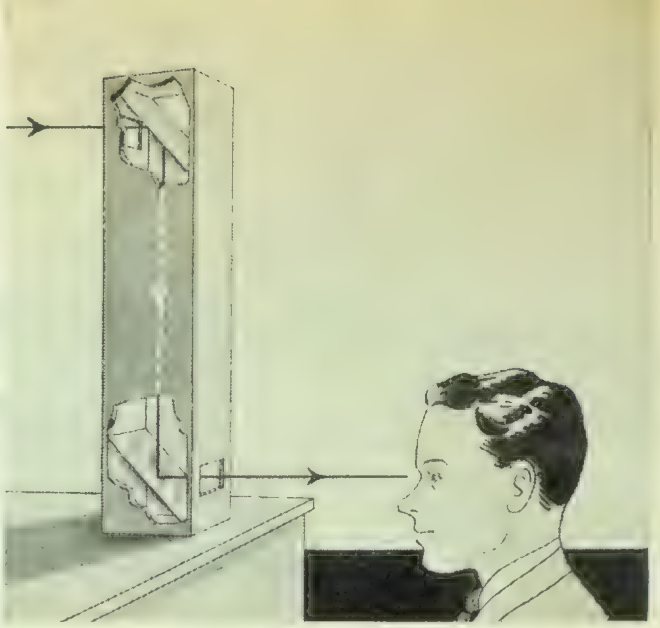

Fig. 458. A periscope

*Experiment 103.* HOW CAN WE PROVE THAT THE IMAGE IN A MIRROR APPEARS AS FAR BACK IN THE MIRROR AS THE OBJECT IS IN FRONT OF THE MIRROR? Set up a sheet of glass in a room that is not too light and where there is no strong light behind the glass. Under this condition the glass will reflect light as a mirror does. Place a lighted candle in front of the glass and an unlighted candle behind the glass (Figure 457). If you look into the glass, you will see the reflection of the lighted candle in front of the glass, and you will also see the real candle through the glass.

Now move the lighted candle about so that its image fits on the image of the unlighted candle no matter from what angle you look at it. Then measure the distance from the glass to the lighted candle and the distance from the glass to the unlighted candle. What do you find?

Watching a circus parade is fun if you can get in the front row where you can see it. Sometimes, however, you cannot see over the heads of the people in front of you. Figure 456 shows one thing that you can do with mirrors to help you look over the heads of a crowd. Do you see the queer-looking boxes? You can understand what they are if you look at Figure 458. This picture shows a *periscope*. It has two mirrors in it, one at the top and one at the bottom. The lines show what happens to the rays of light. The periscope works on the principle that the angle of reflection equals the angle of incidence. Submarines, as you know, use periscopes to see what is going on around them when they are submerged.

So far, we have been talking about *plane mirrors*; that is, mirrors that are not curved. Your father may use a curved mirror when he shaves. If you will look into this mirror, you will see that

it makes your face look much larger. This mirror is a *concave* mirror; that is, it is curved, or caved, inward like a shallow plate. You have surely seen the little mirror on a long handle that the dentist uses. This is also a concave mirror and makes your tooth look larger. Just why this happens is too difficult to explain fully here. In general, it happens because a curved surface reflects light differently from a plane surface.

You can see another way in which curved surfaces affect the reflection of light if you will look at yourself in the polished back of a spoon. Turn the spoon in different ways and see how different you look. This, with the concave mirror, is the explanation for the mirrors that carnival companies have. The back of a spoon is a *convex mirror*. You note that you appear much smaller. An important use of the convex mirror is for rear-view mirrors on trucks and automobiles.

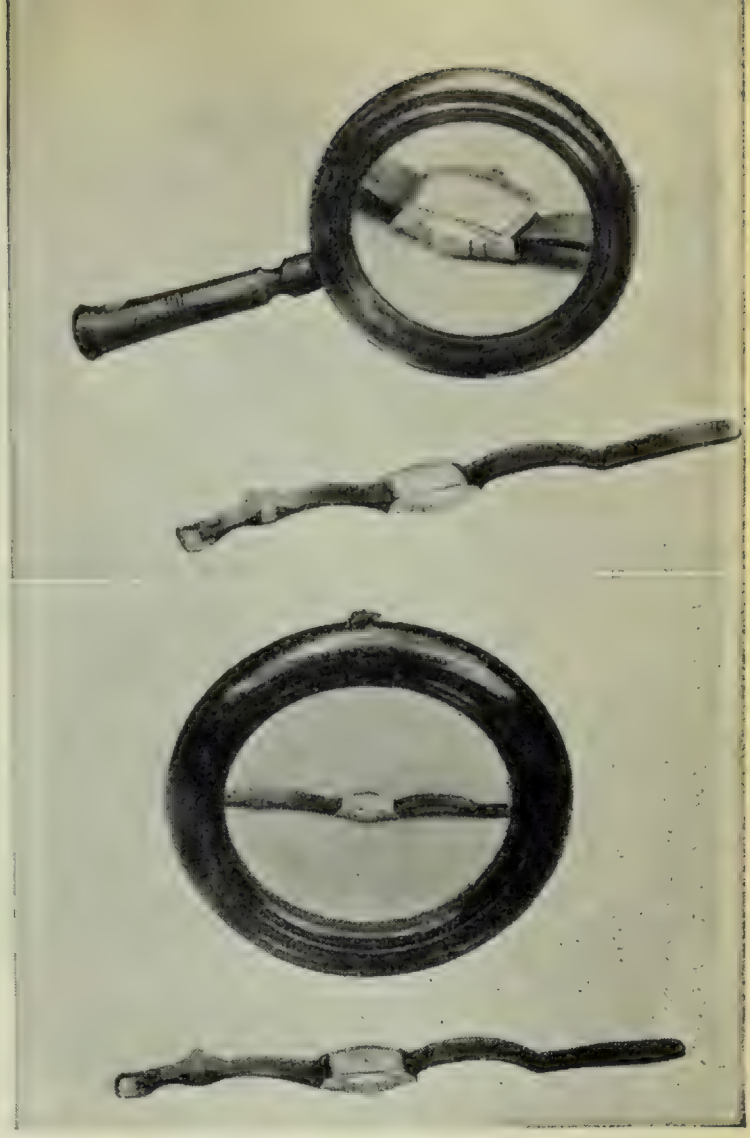

FIG. 459. At the top is a concave mirror. At the bottom is a convex mirror.

*Reflecting telescopes* use concave mirrors. Light from a distant star falls on this mirror. The mirror reflects this light in such a way that all the light collected is concentrated, or *focused*, on a certain point. Therefore it is more intense when it strikes that point. A plane mirror is placed at this point, and it reflects the light through the eyepiece of the telescope. A concave mirror of the correct shape concentrates at one point all the light received over the whole surface of the mirror. See Figure 460 on page 624. This intense light makes it possible to see stars that are not visible in any other way.

*Self-Testing Exercises.* 1. What does Experiment 103 show you about the image that you see in a mirror?

2. Explain how a periscope is made so that you can see around corners with it.


FIG. 460. A reflecting telescope at the Yerkes Observatory, Williams Bay, Wisconsin

3. If you stand in front of a plane mirror, do you look the size you really are or smaller or larger? In front of a concave mirror how would you look? In front of a convex mirror how would you look?

4. Why is a concave mirror used in a reflecting telescope?

*Problems to Solve.* 1. Clothing stores have mirrors arranged so that the customer can see the back and sides of his body at the same time. Make a drawing that will show how these mirrors are arranged. Check your drawing by comparing it with the mirrors in some store.

2. Why can you usually see yourself in plate-glass windows?

3. Some signs along the highway seem to become luminous when they are lighted by automobile headlights. Find out how the signs are constructed. There are a number of ways of making them.

4. Find out how "invisible" show windows work.

5. Hold a brightly lighted pin close to a mirror in such a way that you see the image of the pin at a more oblique angle than is shown in Figure 451. Do you see one or two faint images of the pin in addition to the clear image? Explain why you see what you see.

6. Make a study of the concave mirrors in automobile headlights. What do they do to the light rays? How are the lights changed from "dim" to "bright"?

## 3. How do we use light in our homes?

HOW MUCH LIGHT DO WE NEED IN OUR BUILDINGS? So far as we know, the eyes of man today are no different from the eyes of primitive man, who lived perhaps a hundred thousand years ago. Eyes, like other parts of living things, are adapted to the kind of environment in which a living thing spends its life. The

FIG. 461. The eyes suffer little strain in surroundings like this. (Ewing Galloway photo)

FIG. 462. This is the kind of use that puts a strain on the eyes. (Ewing Galloway photo)

human eye developed in such a way as to adapt itself to the conditions in which man lived. Let us look at these conditions. Primitive man worked or hunted in the daytime. For illumination he used only the direct light from the sun or the diffused sunlight reflected from particles in the air, the trees, the soil, and other surfaces.

To see how much light this is, we need a unit to measure how strong or how intense a light is. The unit used is called a *foot-candle*. A foot-candle is the brightness of the illumination provided by a candle at a distance of one foot. The candle must be just a certain size and burn oil at just a certain rate. You can get a better idea of how much light this is if you will hold a printed page at a distance of one foot from a lighted candle in a dark room. As you can see, a foot-candle is very little light. On a bright sunny day the sun furnishes us with an *illumination* of about 10,000 foot-candles. On a cloudy day, of course, the illumination is much less, but it rarely falls below several hundred foot-candles. On a shady porch on a sunny day the illumination is about 500 foot-candles. Do you see that our eyes are adapted to outdoor conditions in which hundreds or thousands of foot-candles of illumination are available?

Modern conditions have brought about great changes in the way we use our eyes. Our eyes have not changed; they are still best adapted to the kinds of surroundings that primitive man had. Today, however, we do much of our work indoors, where the light is far different from the light out-of-doors. Tests of lighting

conditions in factories have shown surprising results. Even at a distance of a few feet from a window on a sunny day, the illumination may fall to as low as 20 foot-candles. Near the wall, on the other side of the room, only one or two foot-candles of illumination may be present. The kind of work done has also changed. Now most of our work is done at a distance of from one to two and a half feet from the eyes. Furthermore, our eyes are in almost constant use.

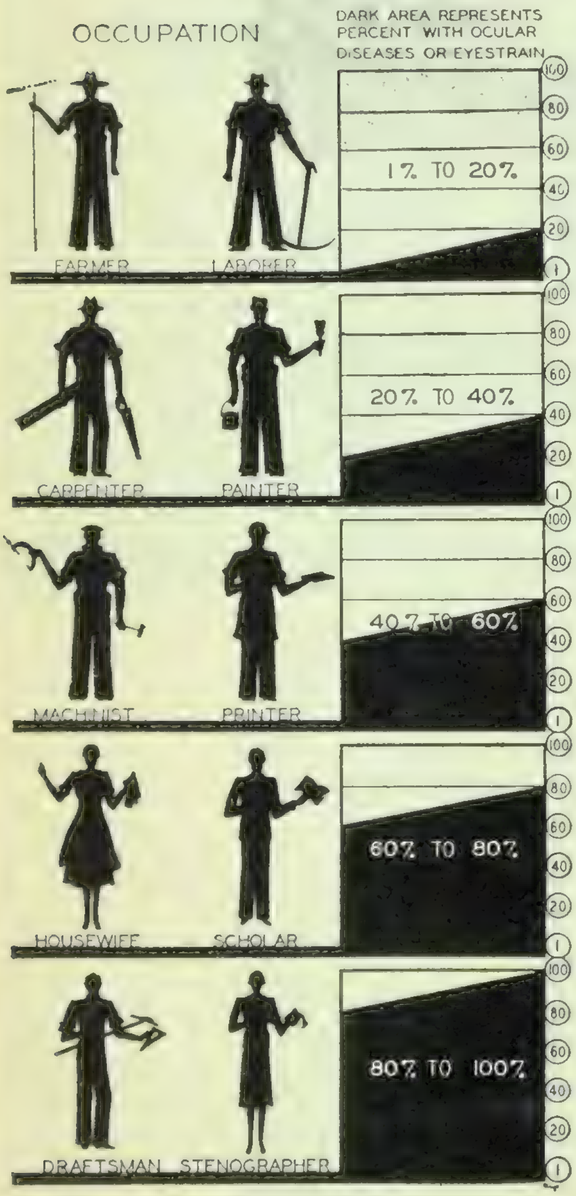


Fig. 463

It is no wonder, then, that so many people have trouble with their eyes. Their eyes are not adapted to the kinds of uses to which they put them. In the United States one out of every five children in elementary schools, two out of every five students in college, and three out of every five old people have defective eyes. Figure 463 shows the per cent of people in different occupations who have eye diseases or eyestrain.

How do we get the right kinds and amounts of light in our buildings? What are we going to do about this constant strain on our eyes? We cannot go back to living in the manner that primitive people lived. Even if our eyes are not adapted to present conditions, we have to use them. There are two things we can do to help our eyes: First, we can learn how to avoid eyestrain. This you will learn about in a later problem. Second, we can provide for the proper lighting of our homes.

With the invention of the *light meter* (Figure 465), lighting has become a science. By this instrument it is possible to tell how much light is needed for different purposes and the kind and number of lamps needed to supply this light. The results of experiments show the following light needs: (1) For use in the dining-room, at a card table, and other eye work not requiring close sight—10 foot-candles or less. (2) For reading good print on

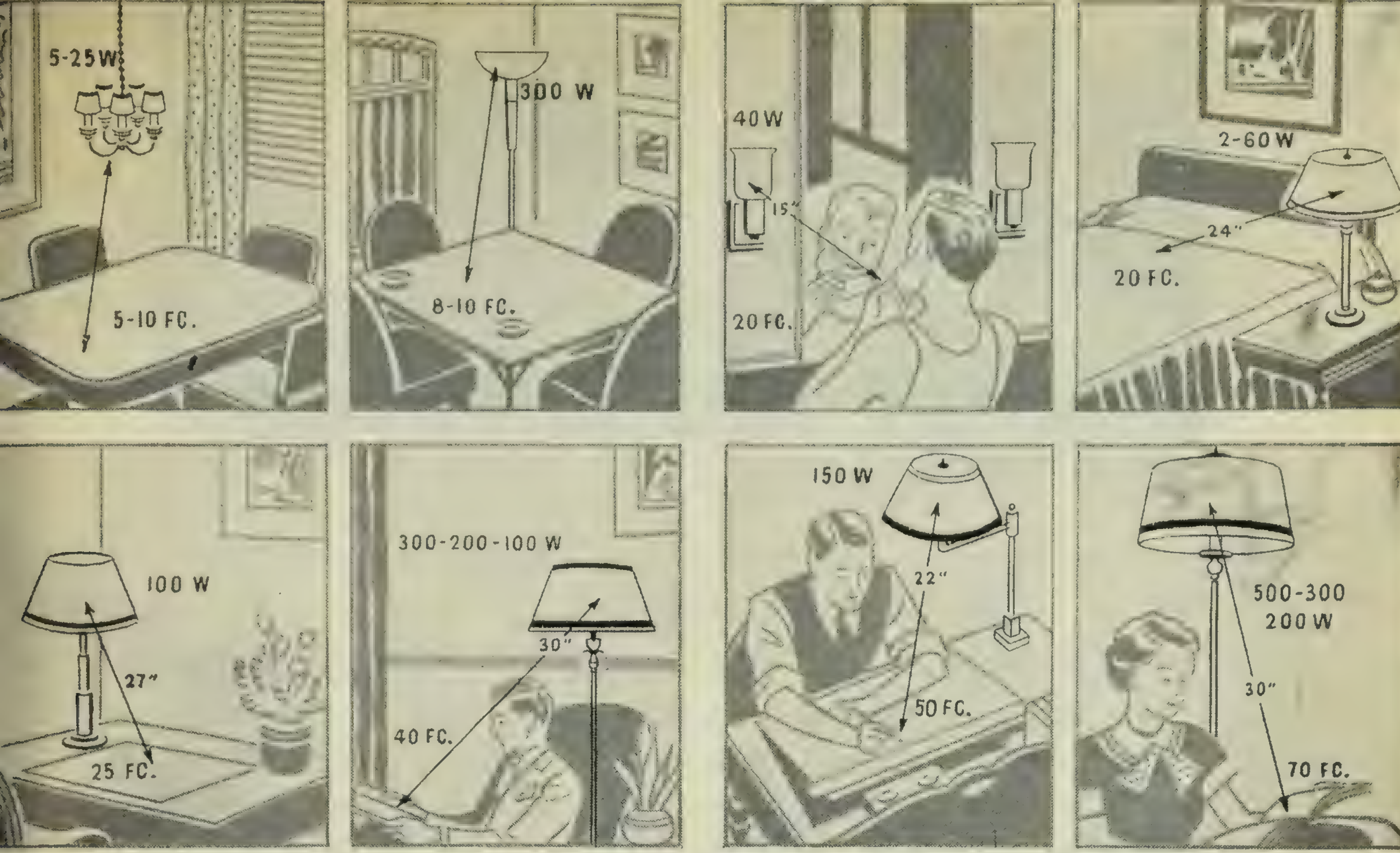


Fig. 464. Study these pictures carefully. They show you how many foot-candles of light are needed for various uses of the eyes and how many watts of electricity are needed.

white paper, coarse knitting, ironing, cleaning vegetables, etc.,—10 to 20 foot-candles. (3) For intensive use of eyes, such as sewing at machines, studying, and drawing—20 to 50 foot-candles. (4) For reading fine print, sewing with dark thread on dark goods, and similar tasks—50 to 100 foot-candles. Study the drawings in Figure 464 carefully.

*Experiment 104.* WHAT EFFECT DOES THE DISTANCE FROM A SOURCE OF LIGHT HAVE UPON ITS INTENSITY? In a dark room place a candle or electric flashlight one foot from a cardboard that has a hole one inch square at the centre (Figure 466). Allow the light to pass through the hole in the first cardboard and strike a second cardboard, which is marked off in square inches and which is held two feet from the candle. How many square inches does the beam of light cover on the second cardboard? Move the second

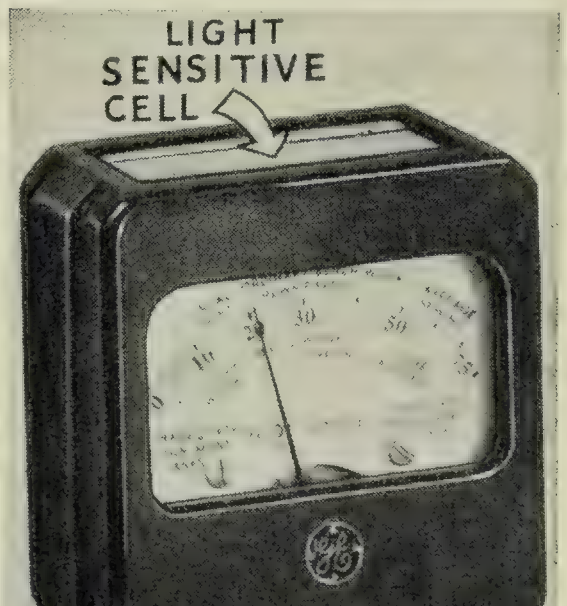


Fig. 465. A light meter (General Electric photo)

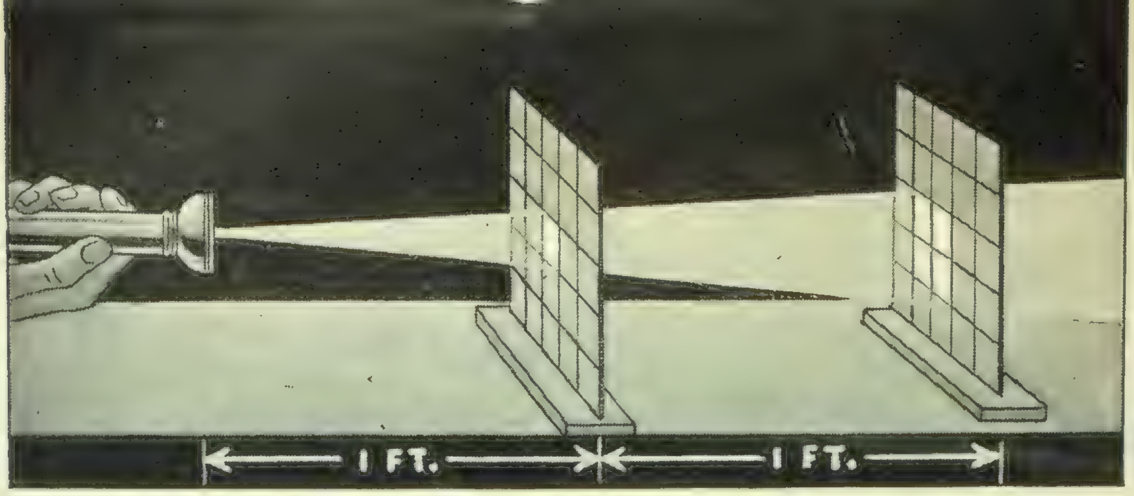


FIG. 466. Apparatus for Experiment 104

cardboard three feet from the candle. How many square inches of space are covered by the beam of light?

From this experiment you see that the intensity of light becomes less as you go away from the source of light. You see that the light is only one-fourth as intense at a distance of two feet as it is at a distance of one foot. This is true, as the experiment showed you, because the light is scattered over four times as much space if the distance is doubled. In other words, at 15 inches a lamp may supply 20 foot-candles of illumination. At 30 inches the same lamp would provide only five foot-candles. In placing lamps it is always necessary to consider the distance from lamp to user.

So far you have been learning about the amount of light needed for work that you are doing. This is called *local lighting*. In addition, there should be *general lighting* for the room. This is usually provided by a central lamp in the ceiling. Lamps in the ceiling are generally of three types. In *direct* lighting the light comes directly from the lamp. Frosted glass bulbs that diffuse the light are much better than plain glass bulbs. In the *semi-direct* method a translucent frosted bowl is placed under the lamp. Some of the light passes through the bowl and is diffused; some is reflected by the bowl to the ceiling and then comes back to the room. This combination of diffused light and diffused reflected light is most pleasing to the eye. It is also more restful for the eyes than direct lighting.

In the *indirect* method of lighting the bowl under the light is opaque, so that no light can come directly to the room. It is all reflected to the ceiling and then comes back to the room. Floor lamps are also made to light a room by this method. This is excellent for general lighting, because the diffused light is very soft and pleasing to the eye.

*Self-Testing Exercises.* 1. To what kinds of conditions are the eyes of man adapted?

2. Make a list of the ways in which you use your eyes. Place an "A" before the ways to which our eyes are naturally adapted and an "N" before the ways to which our eyes are not adapted.

3. Make a drawing that will show why the light is only one-fourth as intense if the distance from the source is doubled.

4. What is the difference between general lighting and local lighting?

5. What is the difference between direct lighting, semi-direct lighting, and indirect lighting?

6. What are the advantages and disadvantages of each method of lighting?

*Problems to Solve.* 1. Make a drawing showing the location and candle-power of the lamps and the location of the furniture in your living-room at home. Compare with the various pictures in Figure 464. Do you think that your living-room is lighted adequately? If not, how could you improve the lighting?

2. Make a drawing that will show why frosted electric lamps give a softer light than bulbs made of plain glass. Explain.

## 4. How do we use lenses?

WHAT HAPPENS TO LIGHT WHEN IT PASSES THROUGH A LENS? Do you know that you are using lenses right now? You need not look for them, because you cannot see them. They are in your eyes. Without them you could not read this book. If the lenses in your eyes are not working right, you probably have a pair of lenses balanced on your nose. You have seen lenses used for other purposes. The simple microscope, or magnifying-glass, that makes small objects look larger than they really are is a lens. The compound microscope that makes it possible to see objects too small to see with the naked eye contains lenses. So do telescopes and field-glasses. Movie projectors use them. The pictures on the motion-picture film are only about the size of a postage stamp, but lenses make them cover a large projection screen many feet away.

If you examine the lenses in these different instruments, you will find that they are all alike in one way: They are merely pieces

of curved glass. They are different only in the way the glass is curved. Different effects are obtained by varying the shapes of the lenses and by grouping the lenses in certain ways.

*Experiment 105.* HOW CAN A LENS BE USED TO PROJECT A PICTURE OF THE OUT-OF-DOORS? Choose a bright sunny day. Get a convex lens, that is, a lens that is thicker in the middle than it is at the edges. Hold the lens in front of a window. Then hold a piece of white cardboard behind the lens at a distance of two or three feet. Bring the cardboard closer and closer to the lens. Watch what happens. Do you see the window and the scene out-of-doors? Is the *image* (picture) you see right-side up or upside down? When the image can be seen most distinctly, we say that the lens is *focused.*

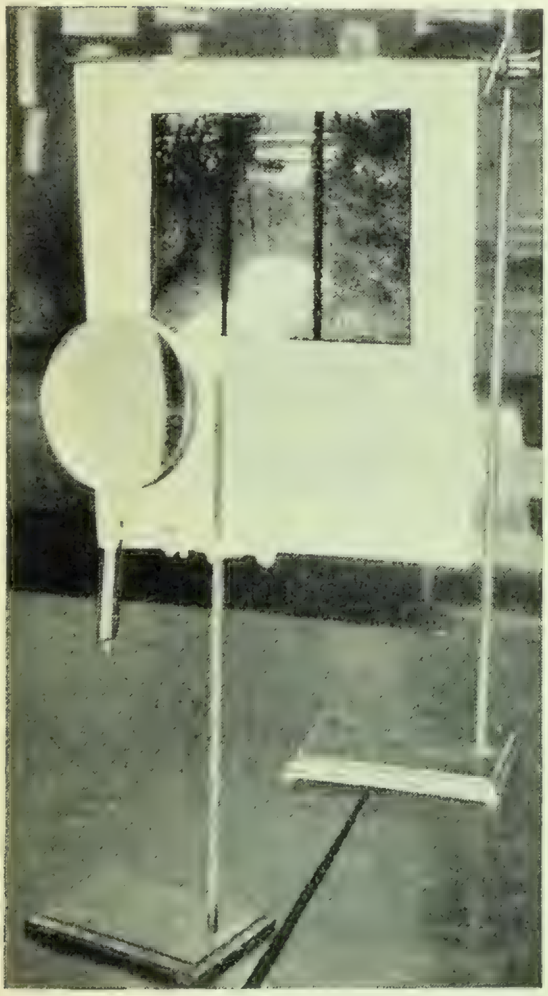

FIG. 467. Apparatus foi Experiment 105

This simple experiment shows you what a lens can do to light. You have a lens in your eye. It forms pictures on the back part of your eye. There is also a lens in a camera. It forms a picture on a sensitive plate or film in the camera. You will learn more about how the eye and the camera work later in this unit. Before you can understand what happens to light as it passes through a lens, you will need to do another experiment.

*Experiment 106.* HOW DO LENSES AFFECT RAYS OF LIGHT? (*a*) Obtain a reading glass (a double convex lens). Darken the room and light a candle. Hold the lens a foot in front of the candle (Figure 468) and then hold a piece of paper back of the lens, where a distinct image of the candle appears on the paper. The candle is then said to be in *focus.* In what way is the image of the candle different from the candle itself? Measure the distance from the lens to the paper.

*b*) Now repeat part *a* of the experiment but place the candle two feet from the lens instead of one foot. Move the paper so that the candle will be exactly in focus. Did you move the paper nearer to the lens or farther from it?

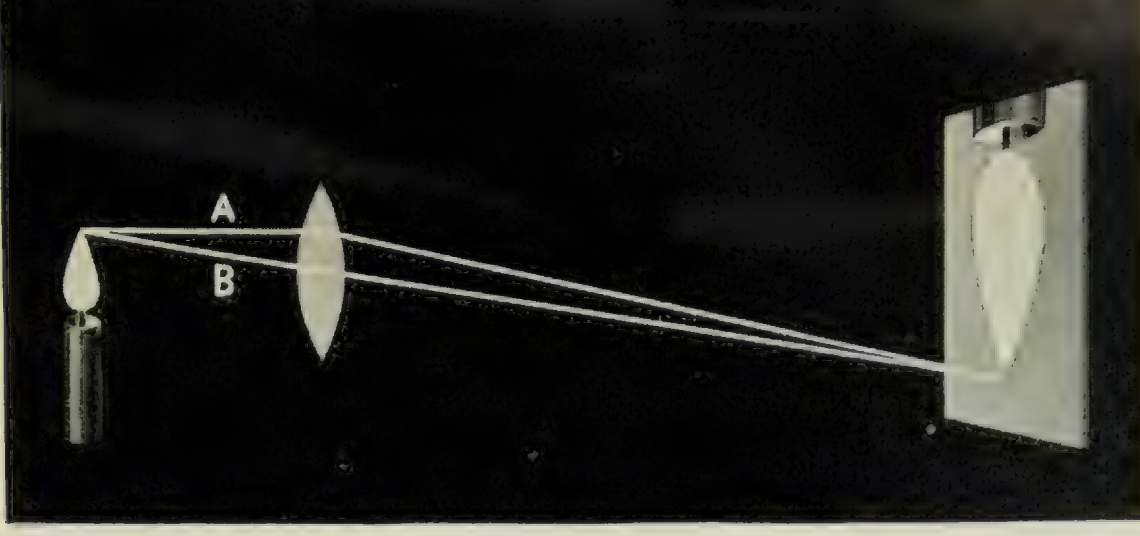

FIG. 468. Apparatus for Experiment 106

c) Repeat part a of the experiment, using a lens that is either more convex or less convex than the first lens. Which lens brings rays to a focus in the shorter distance?

First of all, we must explain why the lens forms an image of the candle on the screen. A diagram will make this clear (Figure 468). We will let lines represent rays of light from the candle. First we will draw line A from the top of the candle flame to the lens. We see by our drawing that the top of the candle comes to a focus on the bottom of the image. Therefore we must draw line A so that it will come to a focus at this point. The continuation of line A will therefore be bent downward. This bending of the light is called *refraction*. We say that the ray is *refracted*. The ray of light, B, that passes through the centre of the lens goes through without bending and intersects line A on the screen.

The point at which these two lines intersect is the focus. All other rays of light that strike the lens from the tip of the candle are bent to come to a focus at the same place. Therefore a bright spot appears on the screen at that point. Light from each other part of the candle acts the same way and is focused at the right point on the screen. All this light from the candle forms the image of the candle on the screen.

Figure 468 shows you that rays of light are refracted, or bent, by a convex lens. That is the reason why the lens can form an image. You have seen that rays of light can be refracted when you used a burning-glass. In this case the rays of sun that strike the glass are bent so that they come to a focus at a certain point (Figure 469). The rays are bent as they pass from the air through the lens because light travels more slowly in glass than in air. Just how this bends the rays you will find out later if you study about the theories of light in physics. You also found in the ex-

periment that the farther away the candle was from the lens, the closer the focus was to the lens. Of course the reverse is true also.

You can see now why you must focus your camera to get a good picture. The camera has a lens, and the rays of light are brought to a focus on the plate or film (Figure 471). To take a picture of someone, you stand far enough away so that you can see the person in the view-finder. The view-finder shows you just what will be visible in your picture. Before you take the picture, however, you must be certain that the rays will come to a focus on the film. You first estimate the distance; then you set your lens for this distance by moving it in or out. A scale on the camera shows you the correct place to set it. Many people think that they have the camera in focus if they see a person in the view-finder. The view-finder, however, has nothing to do with the focus. It merely shows you what you will see in your photograph. The correct focus is obtained by moving the lens in or out.

You also found in your experiment that the thicker the centre of the lens, the more it bent the light rays. In other words, the more convex the lens, the closer the focus will be. You will see later how this idea helps you understand how the lenses in your eyes work.

So far we have been discussing what happens to light as it passes through a convex lens. You have seen that the rays from any point are bent so that they come together at a point (focus) behind the lens. If you use a concave lens, the effect is just the opposite (Figure 472). The rays are bent out rather than bent in. As you can see, such rays cannot come to a focus; therefore a

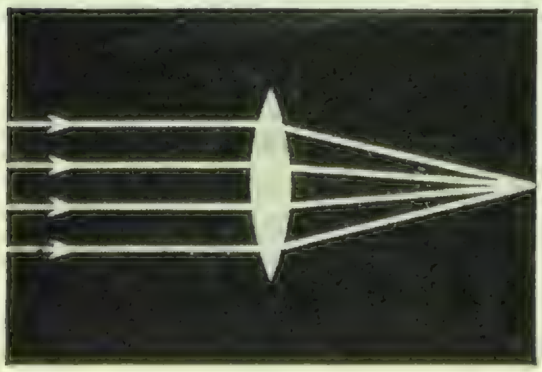

FIG. 469. This drawing shows the focusing of light rays that pass through a convex lens.

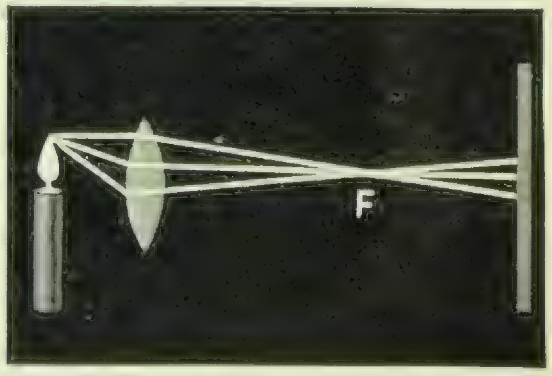


FIG. 470. Which way would you move the lens to make the light rays focus on the screen?

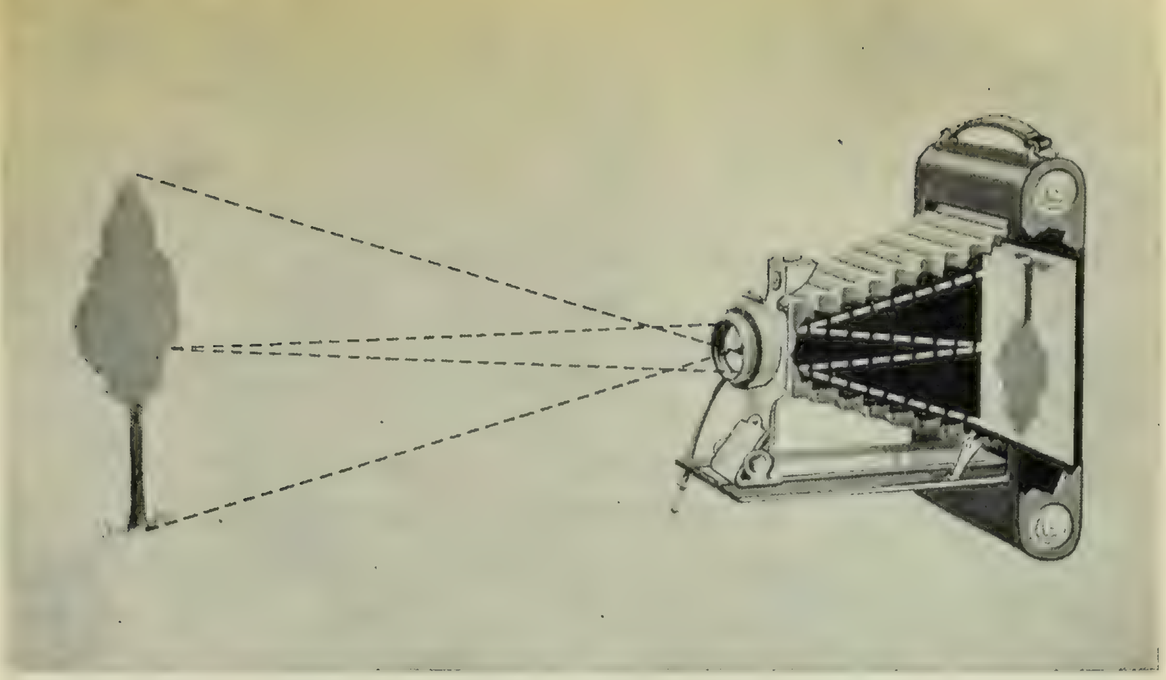

FIG. 471. How the lens of a camera makes an image on the film

concave lens cannot be used to throw an image on a screen. You will see later how some concave lenses are used.

*Self-Testing Exercises.* 1. What is meant by the term "focus"?

2. In what ways does the image projected on a screen by a convex lens differ from the object itself?

3. When an object is moved closer to a lens, how must the screen be moved to put it at the new focus?

4. When an object is moved farther away from a lens, what must be done to the screen to have it at the new focus?

5. How is a camera lens brought to a focus?

6. Suppose that you have two convex lenses, one of which is more convex than the other. Which one would you use to bring the rays to a focus at the shortest distance from the lens?

7. Why is it impossible for you to bring the light rays to a focus with the use of a concave lens?

*Problems to Solve.* 1. How would you perform an experiment to discover which of two convex lenses is the more convex?

2. Remove the back of a camera. Place a piece of glazed paper over the back. Point the camera at some object and then move the lens back and forth until the image is focused on the paper. This will show you why the correct focus must be made in a camera to get a good picture.

3. Why can a convex lens be used as a burning-glass, while a concave lens cannot be so used?

4. Examine a view-finder on a camera. Find out how it works.

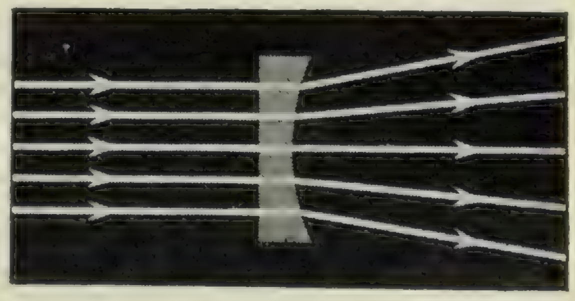

FIG. 472. How rays of light are affected when they pass through a concave lens

5. Fill a small, flat bottle with water. See if you can make it act like a lens. Do the same with a spherical glass flask, or use two watch crystals that are fastened together with adhesive tape and filled with water.

HOW DO WE SEE? You already know that the eye has a lens. It works just like any other double-convex lens. Rays of light are bent and brought to a focus on a thin coat, called the *retina* (Figure 473), which lines the inside of the eyeball. Perhaps you wonder if the images formed on the retina are upside down. Yes, they are. Our brain, however, interprets these images to be in the positions that they really are. So we actually see things as they should be.

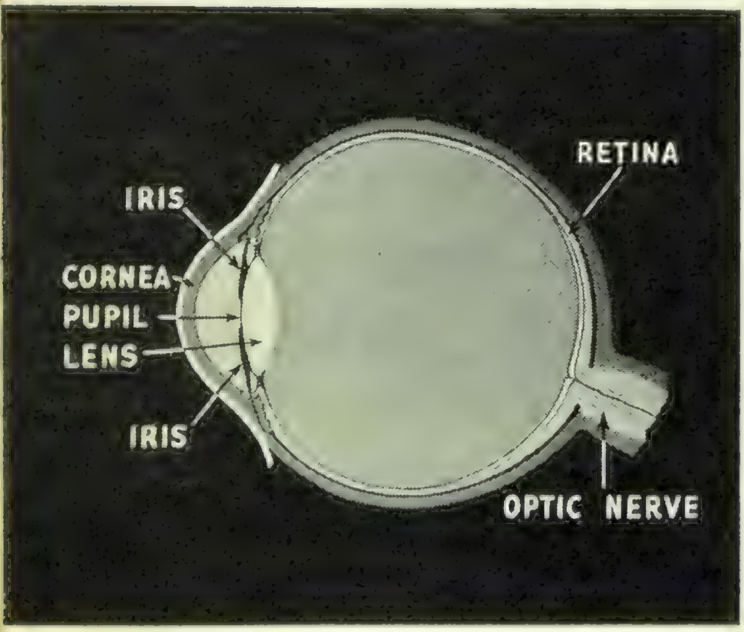


FIG. 473. Diagram of the eye

An American scientist once had a pair of glasses made that would turn the images in his eyes right-side up. When he put them on, a ceiling light looked as if it were on the floor. A flight of stairs leading upward looked as if it were leading downward. For a few days he had a terrible time bumping into things and adjusting his habits to this change. Soon, however, he became adjusted. Things seemed to be where they should be. What do you suppose happened when he took off the glasses? The world was topsy-turvy again. So he had to learn all over. We do not know how the brain interprets things, but this experiment shows that it does. We see things right-side up, even if their images are upside down in our eyes.

If you will hold a pencil in front of your eyes and focus your eyes upon it, you will get a clear picture of the pencil; but you will notice that objects in the background are not clearly defined. Now if you will look beyond the pencil to something in the background, you will see that these objects are quite clear, but that your pencil is not. Your eyes cannot bring two objects at different distances from your eyes into focus at the same time. This you

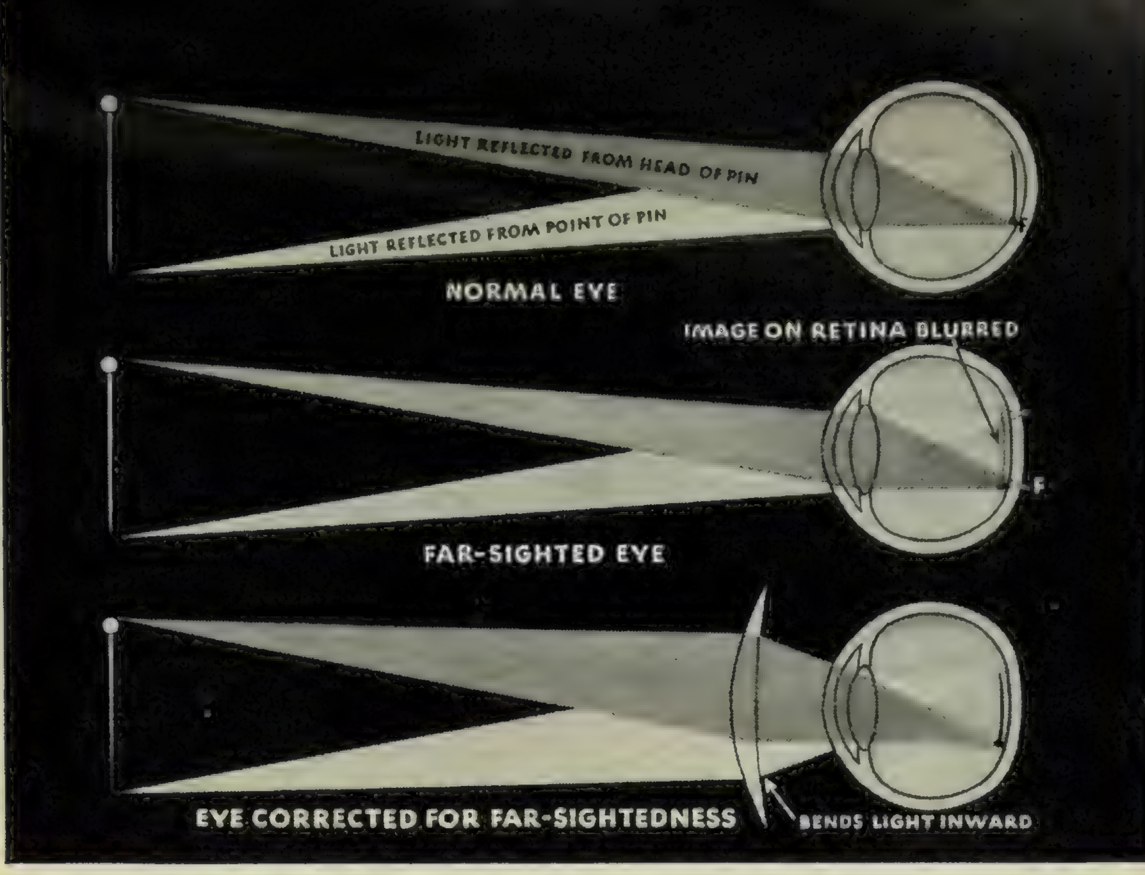


FIG. 474. How the light rays focus in a far-sighted eye. The letter "F" is at the point where the images are brought to a focus.

would expect, because Experiment 106 showed you that objects which are at different distances from a lens are brought to a focus at different distances behind the lens.

This brings us to the question, How can the lens in the eye bring objects at different distances into focus? If you will look at Figure 473, you will see that the lens in the eye is attached at the edge with fibres. At the outer ends of the fibres is a muscle in the form of a circle all the way around the inside of the eyeball. The lens itself is made of a somewhat flexible material that can change its shape. The muscle is attached in such a way that the pull on the fibres to the lens can be changed. When the muscle is relaxed, or loose, the eyeball tends to pull out on the fibres and make the lens flatter and less convex. When the muscle contracts, the fibres are loosened, and the lens becomes thicker in the centre, or more convex.

Now let us see what happens to the lens when you look at a close object. The closer the object is, the farther back the light will be focused. This may be so far back that the eyeball will not be long enough. How can the image be brought to a focus on the retina? To bring it to a focus on the retina, the circular muscle contracts and loosens the fibres that hold the lens. Then the lens becomes more convex. This bends the rays more, so that they focus on the retina. If the object is farther away, the

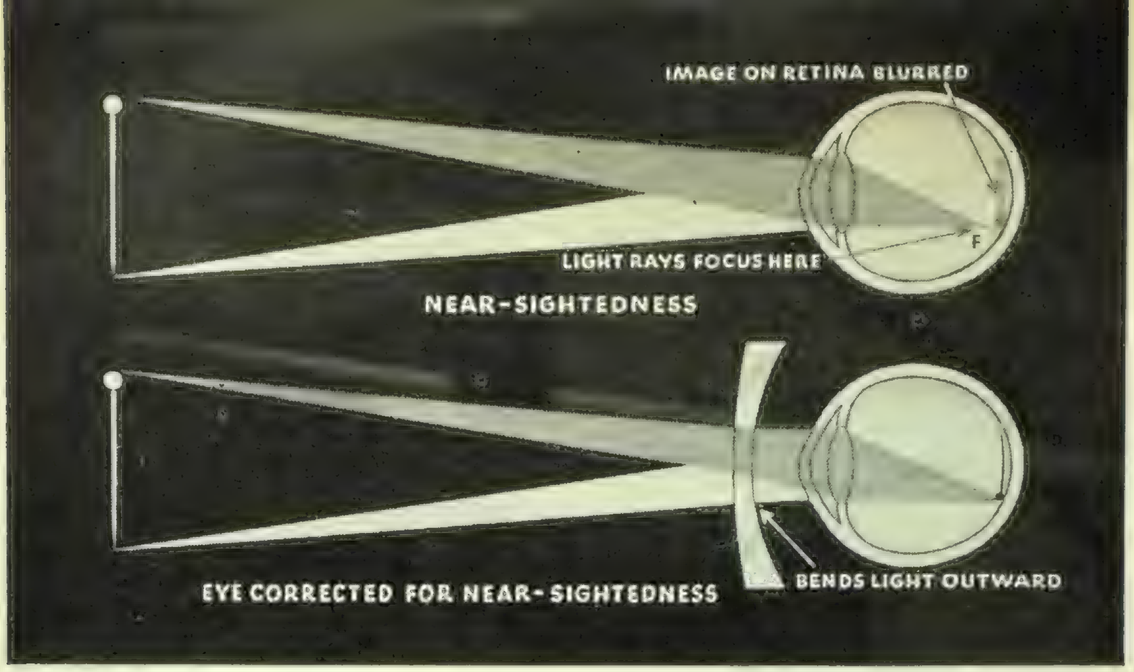


FIG. 475. How the light rays act in a near-sighted eye

muscle relaxes and allows the fibres to pull on the lens, which makes it become less convex. Our eyes thus bring images to a focus on the retina by changing the convexity of the lens.

Unfortunately, our eyes are not always constructed so that a correct focus can be obtained. Some people are far-sighted; that is, they can see distant objects clearly, but not objects that are close at hand. This means that the lens does not focus the light properly. It tends to focus too far from the lens (at F in the far-sighted eye, Figure 474). Sometimes this is caused by the shortness of the eyeball. At other times it is caused by the inability of the lens to adjust itself to near objects. As a person gets older, the lens often loses some of its elasticity, so that it cannot become as convex as it once did. To correct far-sightedness, we wear slightly convex glasses. These convex glasses help bend the light rays in, so that they will come to a correct focus closer to the lens. Thus the image of near objects on the retina is distinct.

The opposite of far-sightedness is near-sightedness (Figure 475). This is caused by conditions that are just opposite to those we have named for far-sightedness. The eye bends the light rays too much, or the eyeball is too long. The light rays tend to focus in front of the retina, and the image of a distant object is blurred on the retina. To correct near-sightedness, slightly concave glasses are used. Some people have what is called *astigmatism*. This may happen when the eyeball is curved somewhat like an egg, instead of being spherical. In such eyes, lines that run in one direction are seen quite distinctly, while those that run in the other direction are blurred. Eye-glasses with lenses that are specially ground can be made to correct this defect.

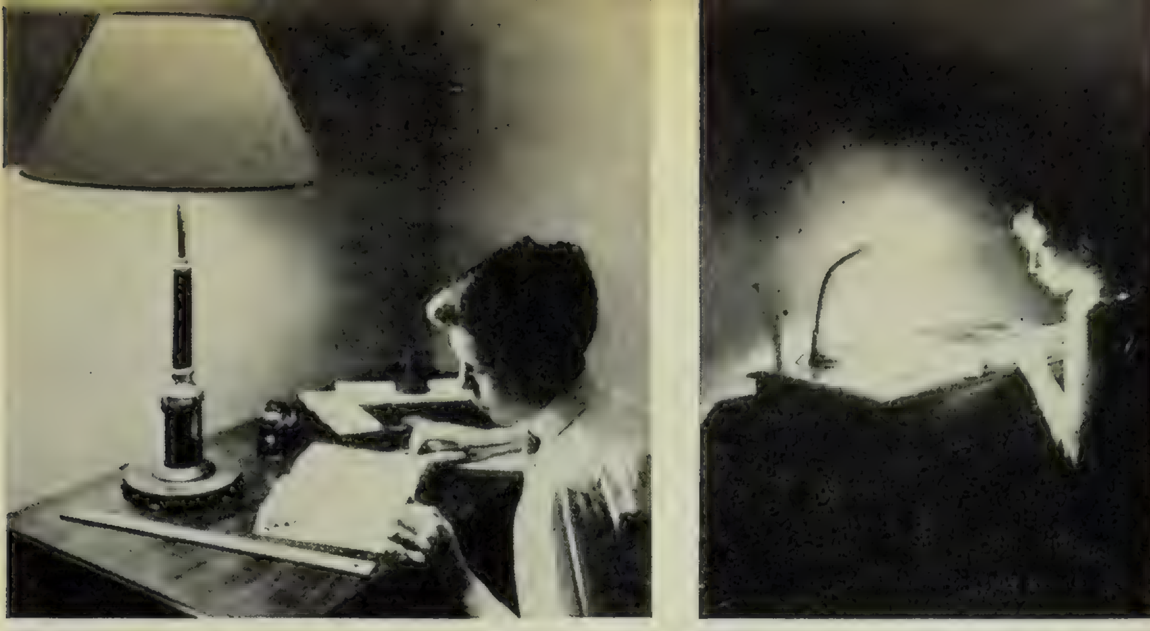

FIG. 476. With diffused light coming from the tall, well-shaded lamp, the boy can see easily and study his lessons without eyestrain. In the other picture there is a glare of light on the book, and some light shines directly into the boy's eyes.

Since your eyes are so important to you, you must take good care of them. First, you should be sure that you do not need glasses. If you find it difficult to read what your teacher puts on the board, or if the writing appears blurred, you may need glasses. For most people a distance of about twenty inches from the eyes is best to get a clear vision of the printed page. If you have to hold your book much farther away or much closer to your eyes, you may be far-sighted or near-sighted. Headaches are often caused by defective eyes, too.

Perhaps you have noticed that your eyes get tired when you read for a long time or do other kinds of close work. When you are reading, the circular muscles around the lenses of your eyes are contracted. After a long time they become fatigued. To avoid this, it is a good practice to look away occasionally and focus your eyes upon some distant object. Too much light or too little light will also cause eyestrain. Figure 476 shows a good way to light a desk. Notice that light does not shine directly from the lamp into the eyes of the boy. Direct sunlight shining on a paper or a book that is being read is especially hard on the eyes of most people.

*Self-Testing Exercises.* 1. How does the eye focus itself?

2. What conditions bring about near-sightedness? How is near-sightedness corrected?

3. What conditions bring about far-sightedness? How is far-sightedness corrected?

4. Why are older people often far-sighted?

5. State three things that you can do to avoid eyestrain.

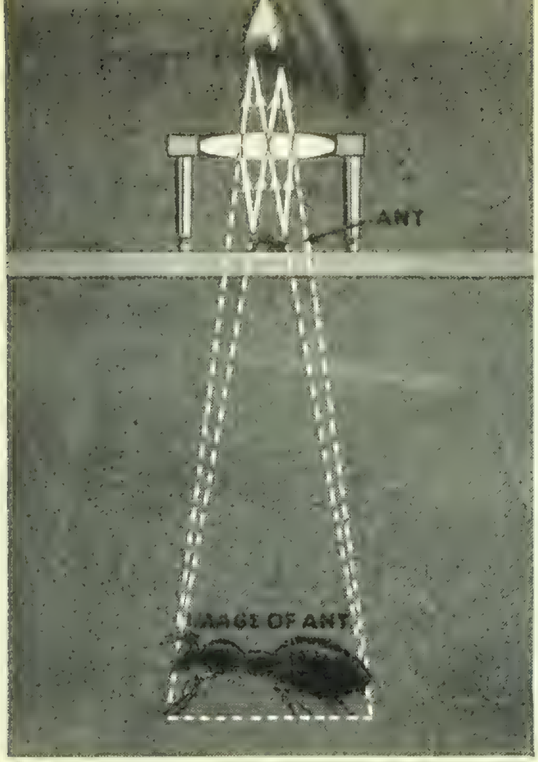


FIG. 477. How light travels through a simple magnifier

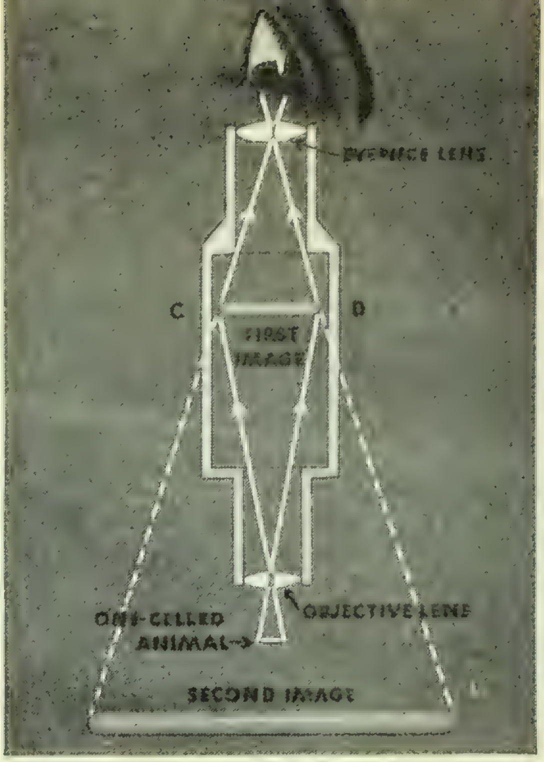


FIG. 478. How light rays travel through a compound microscope

*Problems to Solve.* 1. Devise an experiment to find out if the glasses that you or some friend wears are convex or concave. What does this show about the kind of defect of the eye? Find out if both eyes are defective, or only one eye.

2. Find out what *bifocal* lenses in glasses are and why they are used.

3. When you change from looking at the blackboard to looking at a book, what change takes place in the lenses of your eyes?

HOW ARE LENSES USED IN OPTICAL INSTRUMENTS? Why microscopes magnify and telescopes and field-glasses make objects look nearer is too difficult to explain in this book. We can, however, explain how they are constructed and tell you a little about how they operate. First, let us examine a hand magnifier. It has a double-convex lens. If it is held close to an object, the object appears larger. If you study Figure 477, you can see how the light rays are bent. The rays are bent in when they pass through the lens. But our eyes see the rays as straight lines; therefore what we see is shown by the broken lines. In compound microscopes there are two lenses. Light from the object passes through the *objective lens* and comes to a focus at CD (Figure 478). There is no screen there, but if one were put in, you could see the image just as you did in Experiment 106. The eyepiece then magnifies this image just as it does in the simple microscope.

Telescopes also use two lenses. Light passes through the objective and comes to a focus at CD (Figure 479). This image is then magnified by the eyepiece, as in the simple microscope. The

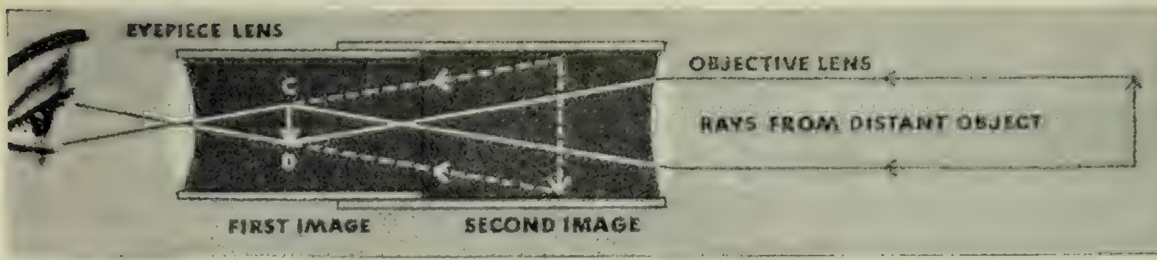


FIG. 479. How the lenses are arranged in a telescope

lenses are mounted in a sliding, or telescoping, tube so that the image can be brought into correct focus for objects at different distances. The image is inverted, and for this reason you see the object upside down. Some telescopes have another lens that makes the image right-side up. Some field-glasses and opera-glasses use a combination of lenses and *prisms*. A prism is a triangular-shaped piece of glass. The combination of prisms used is known as a *reversing prism*. In such a prism the light is reflected four times. These reflections turn the image right-side up. This kind of field-glass is very compact. By the use of prisms field-glasses have a magnification equal to a telescope that is three times as long.

Motion-picture machines also have a combination of lenses to project a picture on a screen. First of all, a powerful arc light or an electric bulb is used to supply the light. This light is concentrated on the film by a convex lens. On the film are countless separate pictures, each of which is about one inch long and about three-fourths of an inch high. In front of the film is a lens that forms an enlarged image on the screen. An electric motor is used to draw the film along at the rate of about sixteen pictures per second. As each picture appears in front of the light, it stops for about one thirty-second of a second. While the picture is still in front of the light, a shutter opens and allows light to pass through the picture. When the film starts to move again, the shutter is closed so that no light can pass through the picture. Then the shutter opens, another picture is seen, and so on. (See Figure 480 on the next page.)

What you really see, therefore, is sixteen still pictures per second. The pictures are shown so quickly that it appears as if the figures were moving. Actually, of course, the figures are not moving. Our eyes cannot instantly "forget" what they see. Each

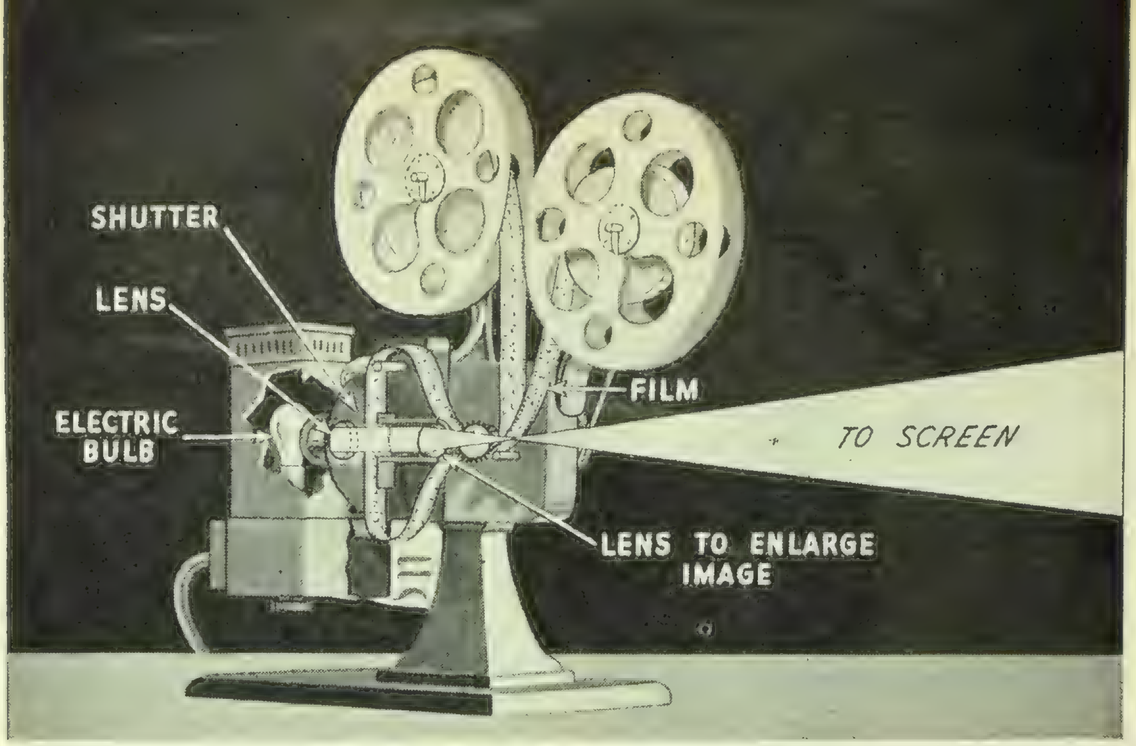


FIG. 480. Diagram of a motion-picture projector

image leaves a picture on the retina for a fraction of a second. Before one image has faded from the retina, another is formed. As a result, each picture blends with the next, and you get the effect of continuous movement.

*Self-Testing Exercises.* 1. Make a drawing showing how a simple microscope makes a pin look larger. Use Figure 477 as a guide.

2. Make a drawing that will show how a compound microscope makes a pin look larger. Use Figure 478 as a guide to follow.

3. Explain how a motion-picture projector works.

*Problems to Solve.* 1. Explain why motion pictures flicker if the film is run too slowly.

2. If a motion-picture projector produces a picture that is too large for the screen, should the projector be moved nearer to or farther from the screen?

3. Olives look much larger in the bottle than they do when out of the bottle. Explain.

4. Prove that a motion-picture screen is not lighted all the time. To do this, move your hand back and forth rapidly before your eyes while you are watching a movie. What do you notice? Explain.

5. Learn how slow-motion moving pictures are made.

## ¶ 5. Why are objects of different colors?

BEFORE YOU TRY TO ANSWER THIS PROBLEM, recall some of the experiences you have had in order to find some facts about color. Did you ever notice that a soap bubble has many different colors? You have probably seen these same colors reflected from

oil on the pavement, or you may have seen them in a flaw in window glass. Can you explain how these colors are produced?

Perhaps you have noticed that things appear to be different in color under artificial light and in sunlight. If you choose a tie or dress under artificial light, you may be surprised to find that it looks quite different in the daylight. Curious things happen when you look at different colors under different colored lights. White paper looks white in the sunlight. If you throw a red light on it, it appears red; in a green light it looks green. A red dress in a blue light appears black. A blue dress appears black under a red light. These facts raise an interesting question: "Why do objects not always have the same color?" To answer the question, you will need to find out more about light.

*Experiment* 107. WHAT COLORS DOES SUNLIGHT CONTAIN? Pull down the shade of a window so that only a narrow beam of sunlight can enter the room. Darken the rest of the room. Hold a glass prism in this beam of sunlight and put a white cardboard behind it (Figure 482). What do you see?

The band of colors that you see is called the *spectrum*. The spectrum consists of seven colors—red, orange, yellow, green, blue, indigo, and violet—that blend gradually into each other. These are the same colors that you see in the rainbow. If a reading glass is held in just the right place in the path of the rays that pass from the prism, the colors will disappear, and only a white spot will be seen on the screen (Figure 483). By now you are probably curious as to where these colors come from. They come from the white light of the sun.

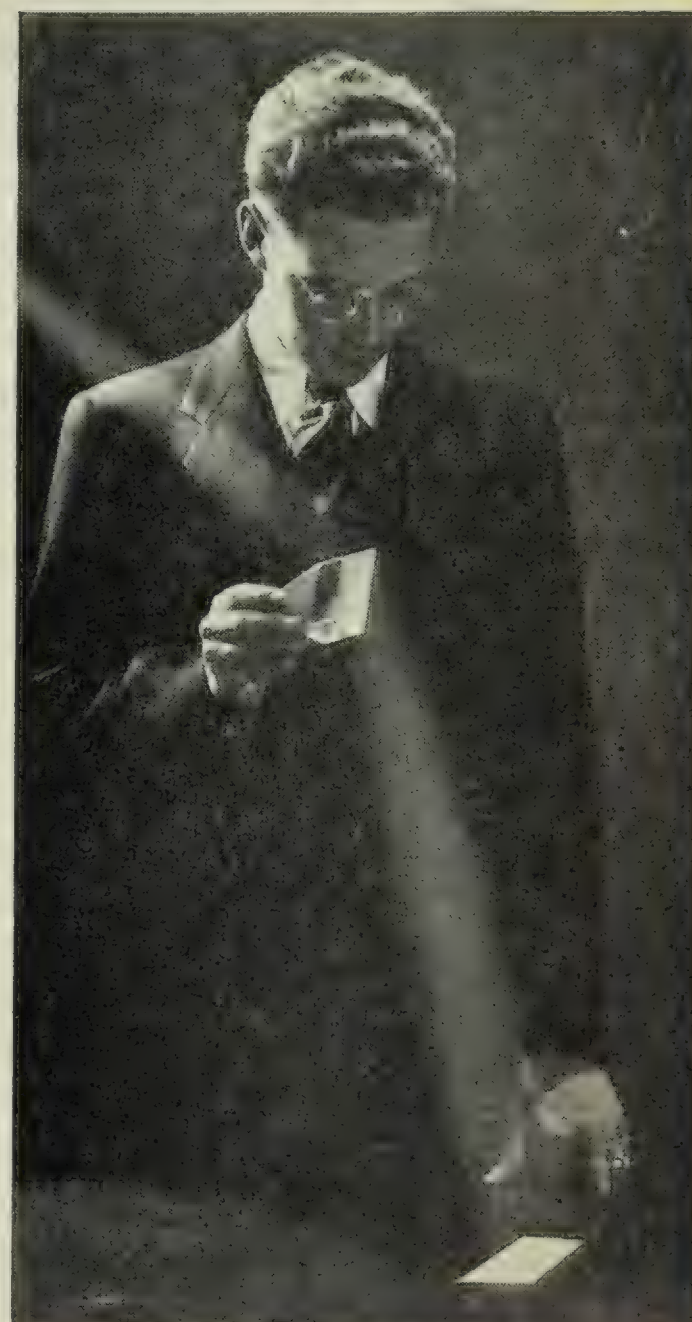

FIG. 481. How a prism bends light rays (Photo from *Nature Magazine*)

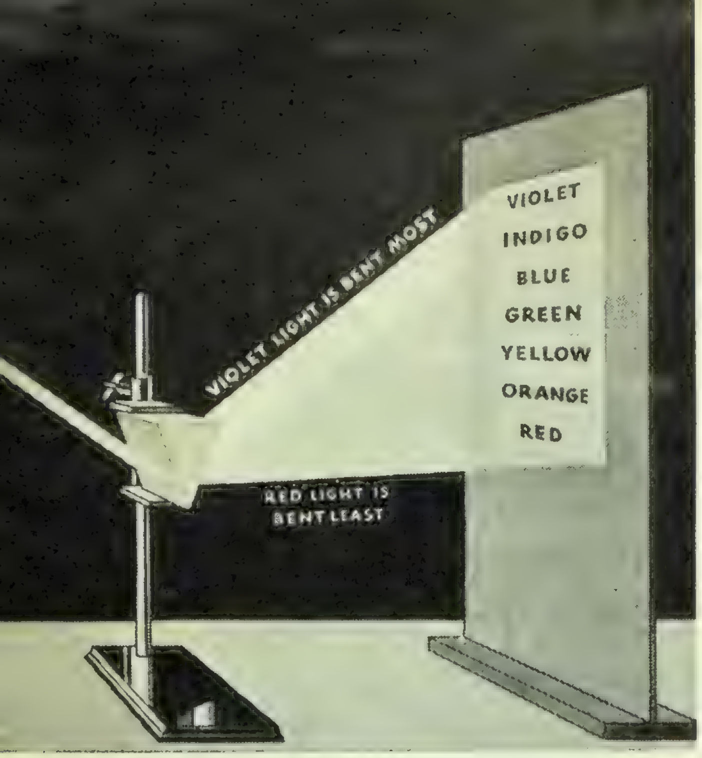


Fig. 482. How a prism separates the rays of light


Fig. 483. How a reading glass mixes the colored rays to make white again

White light is really a mixture of these seven colors. The prism separates the complex white light into the different colors of which it is made.

Light is believed to travel in waves. These waves are somewhat like the waves of the ocean that you may have seen rolling into shore. Some of the waves are long; that is, the distance between the crests of two waves is long. Other waves are short. In a like manner, each kind of color light has its own wave length. The wave length of red is .000028 inches. The wave length of violet is .000016 inches. If you will look at the colors made by the prism again, you will see that red is at one end of the spectrum, and violet is at the other end. The wave lengths of the other colors are in between those of the red and the violet.

You know already that light waves are bent where they pass into glass. Different kinds of light waves (colors) are bent differently. The shortest light waves are bent more than the longer light waves. You can see, therefore, that violet light will be bent more than the red light. Since each kind of light wave is bent differently, the result will be bands of the different colors on the screen (Figure 482). Did it surprise you to learn that white sunlight is really a mixture of all the colors of the rainbow? You saw, however, that the colors could be mixed again to produce white light when a reading glass was held behind the prism.

As yet, we have not explained why objects differ in color. A white paper is white because it reflects all of the colors in sun-


FIG. 484. How rays of light are reflected from different kinds of material

light equally. None of the colors is removed from the light; so the light that is reflected to our eyes is white light. A dress appears green because the dye in the dress absorbs all of the colors in the sunlight except green. The green is reflected to your eye; thus you see the dress as green. If a green dress is held in red light, it looks black. The green dye can reflect only green, and unless the dress is held in some light that has green in it, the dress cannot appear green. You can see, therefore, why objects are colored. They have a certain color because they take out, or absorb, all the other colors in white light. If they absorb all colors, then they are black (Figure 484). If they reflect all colors, they are white.

It is not quite correct to say that a green paint will absorb violet, indigo, yellow, orange, and red, and reflect only green. Most of the dyes and pigments that we use in paint are not true *spectral* colors; that is, they are impure colors. For example, a yellow paint usually reflects some green as well as yellow. More yellow than green is reflected; so it appears to be all yellow. A blue paint will also reflect some green. When yellow paint and blue paint are mixed, the resulting color is green. Let us see why. The yellow paint will absorb blue light, and the blue paint will absorb yellow light. Since the green light is not absorbed by either paint, it is reflected, and we see the paint as green.

Colors usually appear different under artificial lights from what they do in sunlight because artificial lights have less blue in them. As a result, blue looks very dark under artificial light. This is true because there is less blue to be reflected. Artificial lights have more red in them than sunlight. Red, therefore, looks much brighter because there is much red to be reflected. Many clothing stores have what they call daylight lamps to help their customers

in selecting colors. These lamps supply an artificial light that is much the same as sunlight.

*Self-Testing Exercises.* 1. Describe an experiment to prove that white light is really a mixture of many colors.

2. Why does a prism separate white light into the different colors?

3. What determines what color an object will be?

4. A white dress will appear red in a red light and blue in a blue light. Explain.

5. Why do objects appear a different color under artificial light than they do in daylight?

*Problems to Solve.* 1. If a black object absorbs all of the rays of light that it receives, how can we see it?

2. Why can you often see colors in a diamond or in a cut-glass dish?

3. Find out how colored motion pictures are taken.

4. How do drops of water make a rainbow? Read the explanation in a physics book.

5. Study Figures 481 and 482. Explain how the glass in Figure 445 can show what is on the other side of the hill and yet not be a mirror.

## Looking Back at Unit 18

1. Write a list of what you consider to be the most important ideas in this unit.

2. What questions were answered in this unit that you wanted answered?

3. Show that you know the meaning of the following terms:

| | | |
|---|---|---|
| *luminous material* | *reflected light* | *opaque material* |
| *transparent material* | *angle of incidence* | *translucent material* |
| *diffused light* | *regularly reflected light* | *angle of reflection* |
| *focus* | *direct lighting* | *foot-candle* |
| *indirect lighting* | *convex mirror* | *semi-direct lighting* |
| *image* | *convex lens* | *concave mirror* |
| *retina* | *astigmatism* | *concave lens* |
| *near-sightedness* | *spectrum* | *far-sightedness* |

## Additional Exercises

1. A yardstick held in a vertical position has a shadow eight inches long. A tree at the same time has a shadow ten feet long. How can you find out the height of the tree?

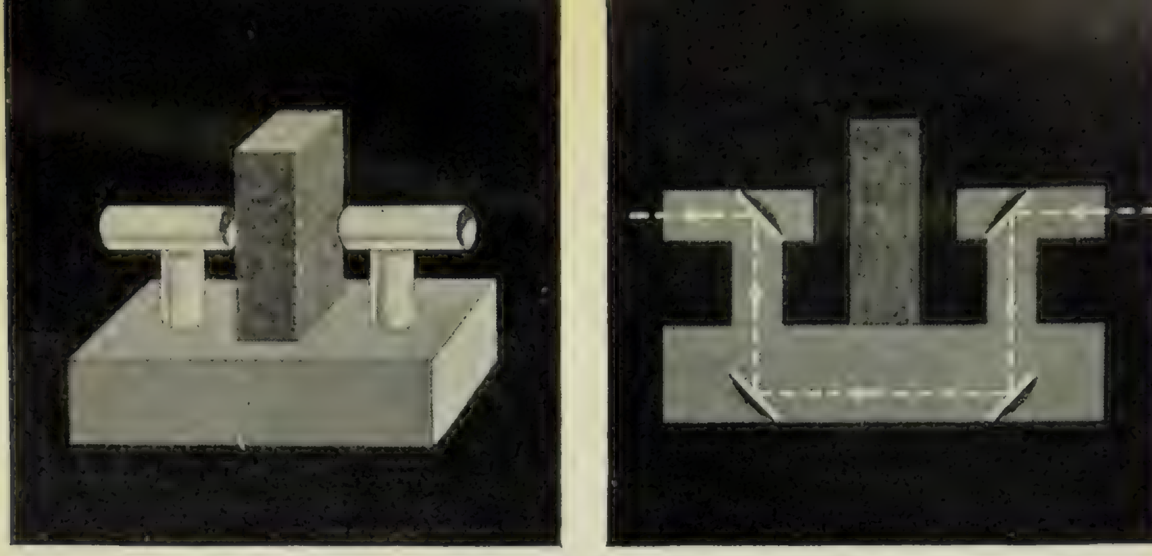

FIG. 485. Apparatus for Additional Exercise 4

2. Examine a camera. Find out the purposes of the different adjustments. Make a report to the class.

3. Make a pinhole camera. Cut out one end of a pasteboard box and paste a piece of white tissue paper or tracing paper over this end. Bore a tiny hole, like a pinhole, in the centre of the other end of the box. Set the box with the pinhole facing an open window. Throw a dark cloth over your head so that no light can get to your eyes except that which comes through the pinhole. What do you see on the tracing paper?

4. Can one see through a brick? You can make it seem as if it is possible if you will arrange an apparatus like the one shown in Figure 485. You can make the tubes of cardboard, and you will have to bore holes in the board as shown by the dotted lines. The only difficult part of the apparatus is getting the mirrors at the right angles.

5. Find out what a rapid or fast lens of a camera is, and how it is different from a slow lens.

6. If someone in your class is a good photographer, have him explain just how cameras are adjusted to get the correct exposure of the film to light.

7. How is a light meter used in taking pictures?

8. Find out what is meant by the *speed* of a camera film?

9. Find out how color film is made and how all the different colors are produced in the final picture.

10. Appoint a committee to investigate the small eight-millimetre and sixteen-millimetre motion-picture cameras. How do they work? How long is each separate picture exposed to light? How many pictures per second do they take?

## Books to Read


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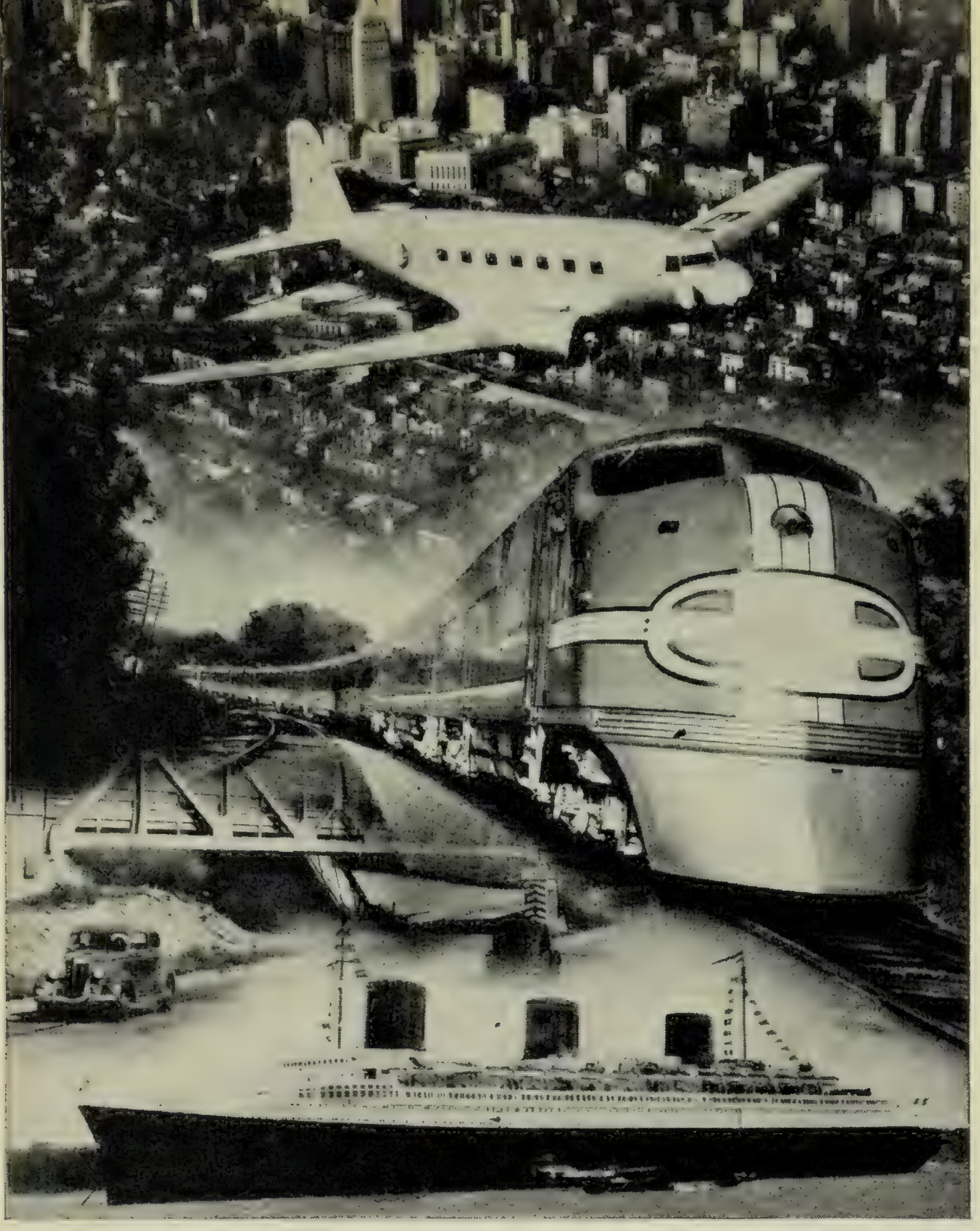

To use the energy of a horse for transporting materials and people, we have to harness the horse in some way. As you learned in Unit 15, to use any kind of energy we must have a harness for the energy. Steam engines, gasoline engines, and Diesel engines are harnesses that we use to help us move people and materials on land, on water, and in air. In our country today, about 90 per cent of our nation's horse-power is used for transportation, for moving people from place to place and for distributing goods. (Kaufman-Fabry photo)

# UNIT 19

# How Do We Provide Transportation?

## Looking Ahead to Unit 19

If you compare how people live today with how they lived 100 years ago, you realize that our present ways of living are possible only because of speedier and more dependable methods of transportation. Things that are considered the necessities of life today were regarded as luxuries 100 years ago because of the time and the expense it took to get them. Your clothing, food, and home are different because of modern transportation. You eat apples from Nova Scotia, dates from Egypt, nuts from Brazil, wheat from the prairie provinces, and cheese from Ontario and Quebec. The material from which your clothing is made may have grown on a sheep's back in Australia or New Brunswick. Your house may be constructed of lumber from British Columbia, stone from Indiana or Manitoba, and glass from Ontario, and furnished with materials that have come from all parts of the world. This has been made possible by the development of land and water transportation.

You have already studied about the workings of the gasoline engine, the steam engine, the Diesel engine, and the electric motor. It was the invention of these machines that so greatly changed our methods of transporting ourselves and our materials. Two hundred years ago land vehicles were propelled by man power and animal power. Boats and ships were propelled by the wind. The aeroplane and the dirigible were unknown. Today by aeroplane we can travel from London to Bombay more quickly than our ancestors could travel from London to Edinburgh by stagecoach. There has been just as great a change in the speed of water transportation. It took Columbus sixty days to cross the Atlantic Ocean; a modern ocean liner can cover this distance in four days, and dirigible airships have covered the distance in three

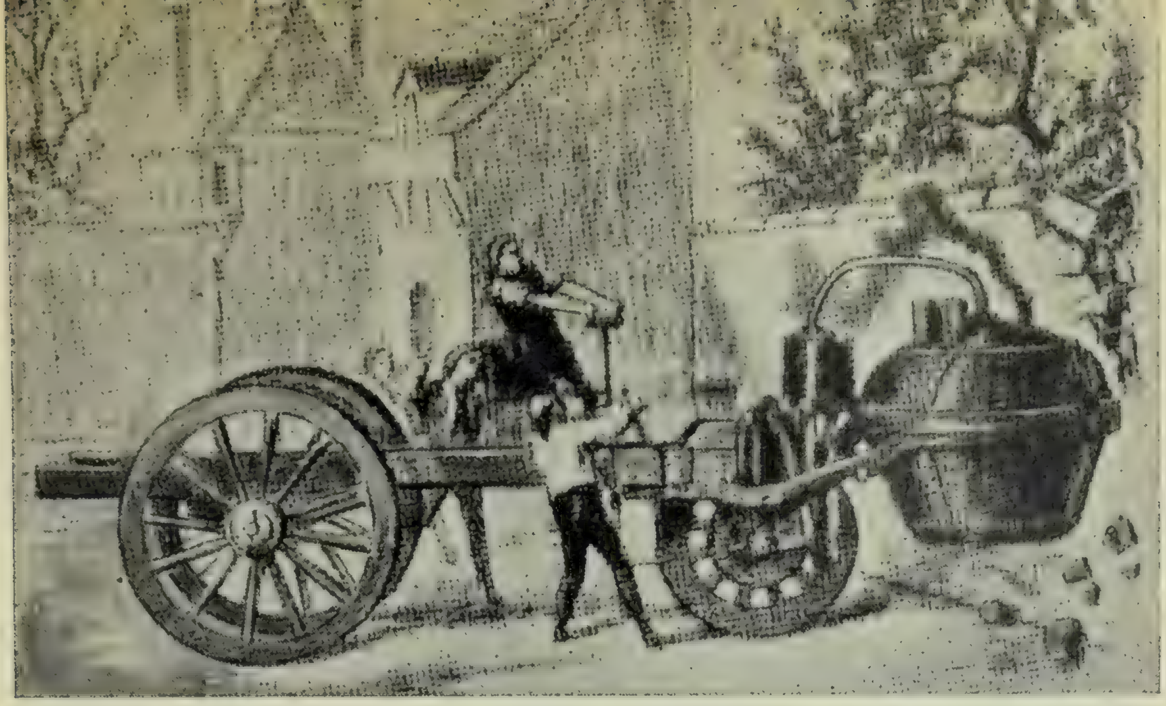

FIG. 486. This picture is made from an old drawing of Nicholas Cugnot's steam locomotive. The machine travelled on ordinary roads at a rate of about three or four miles per hour, and it had to stop every ten minutes to get up steam. Apparently the "engineer" had a hard time steering it.

days, and "Clipper" aeroplanes make the trip in about twelve hours. All of these changes have come from the harnessing of the energy of steam, exploding gas, and electricity.

But it took more than the invention of these engines to bring about their use for transportation. The steam engine was first put to practical use in about the year 1700, but it was not until 1769 that a vehicle propelled by steam was invented. Nicolas Cugnot, a French army officer, was the inventor (Figure 486). In 1829 George Stephenson invented his *Rocket*, a successful locomotive run on rails, and in 1837 the first Canadian railroad was in operation. The use of the gasoline engine has had a history somewhat like that of the steam engine. The first practical gasoline engine was invented in 1876, but it was not until 1887 that such an engine was used to drive a vehicle.

Another chapter in the history of transportation is that of the progress in transportation by water. A part of this progress came as a result of the discovery of how and why things float. From this discovery man has been able to build larger and larger ships and to construct them of strong materials such as iron and steel. In addition, progress has been made in developing methods of propelling boats. On small boats gasoline and Diesel engines have taken the place of the heavier steam engine, especially in lake and river transportation. In this unit you will want to learn why steel ships can float and how engines can drive them through the water.

FIG. 487. *The Constellation*, a four-motor all-metal plane, carries fifty-one passengers and a crew of five. Flying over six miles a minute, it can cross our country in about seven hours. (T.W.A. photo)

The idea of flying has always appealed to the imaginations of men. But some of the problems of transportation in air have been harder to solve than the problems of transportation on land and on water. One of these problems is how to support the vehicles in which we ride and carry our goods. Many materials will float in water. Only a few materials are light enough to float in air. And dirigible balloons have to be filled with such large quantities of gas that they are unwieldy and hard to control. To get rapid and easily controlled flight, inventors had to apply an entirely new principle. But they have been successful, and every day thousands of people fly long distances in aeroplanes that weigh much more than the air about them. In this unit you can learn how the great planes are pulled through the air and what keeps them up.

## ¶ 1. How are land vehicles propelled?

HOW DOES A STEAM ENGINE RUN A LOCOMOTIVE? You have already learned how the backward and forward motion of the piston of a steam engine is changed into the motion of a flywheel in the stationary steam engine. In the locomotive the *driving wheels* take the place of the flywheel of the stationary steam engine. The ordinary locomotive has two engines, one on either side in front of the driving wheels and just outside the small

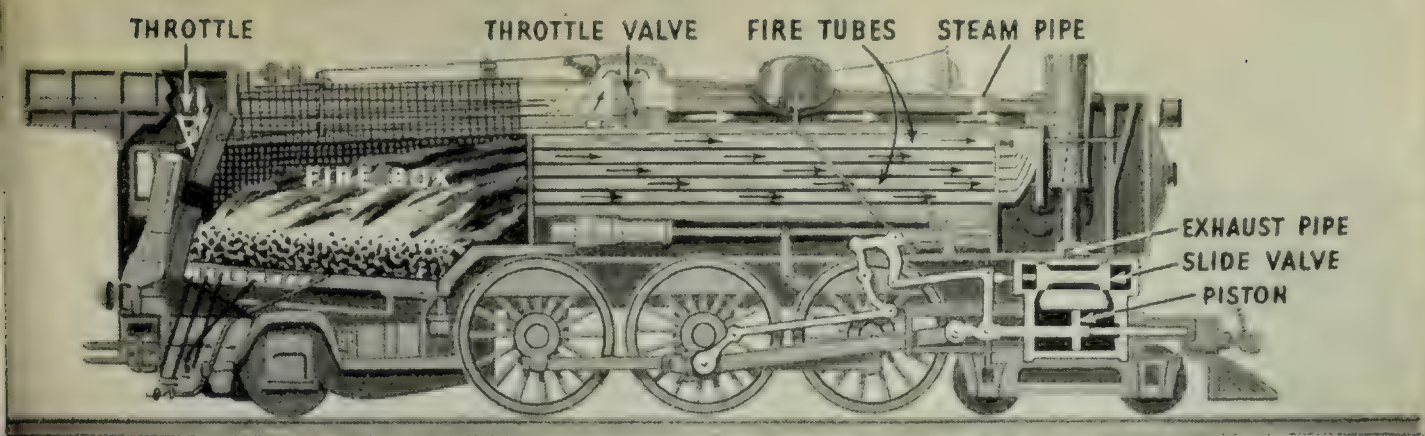


FIG. 488. Study this drawing carefully and be sure that you can explain its parts. The *sand dome* is on the top of the locomotive between the throttle valve and the bell.

wheels. An arrangement of levers connects the slide valve of each engine with an eccentric on one of the driving wheels. A connecting rod connects the piston rod to the eccentric.

If you will study a locomotive, you will see that the power of the steam engine is transmitted directly to the driving wheel. There is no system of gears such as is necessary in the automobile. The force of the expanding steam can be applied directly to the driving wheels because steam develops its full power as soon as it enters the cylinder. As you will learn in the next sub-problem, this is quite different from the gasoline engine. The amount of power developed by the steam engine depends upon the quantity and pressure of the steam that enters the engine.

A long, heavy bar, called the *Johnson bar*, is attached to the eccentric on the middle drive wheel and to the eccentrics of the other drive wheels. As the steam drives the piston back and forth, the drive wheels begin to rotate. The locomotive is very heavy, and it presses down on the track with great force. This causes such great friction between the wheels and the track that the locomotive is forced to move. If the track is slippery, it can be "sanded" by allowing sand to trickle from the *sand dome* through a pipe which opens in front of the drive wheels.

The pistons, slide valves, and eccentrics in the two engines on either side of the locomotive are so arranged that when one engine is passing the deadpoint, the engine on the other side is exerting its greatest force in turning the wheels. The locomotive therefore cannot stop both engines at their deadpoints. A deadpoint is exactly at either end of the cylinder. In these positions the piston is pushing or pulling on a straight line against the axles of the drive wheels. Therefore it cannot turn the wheels.

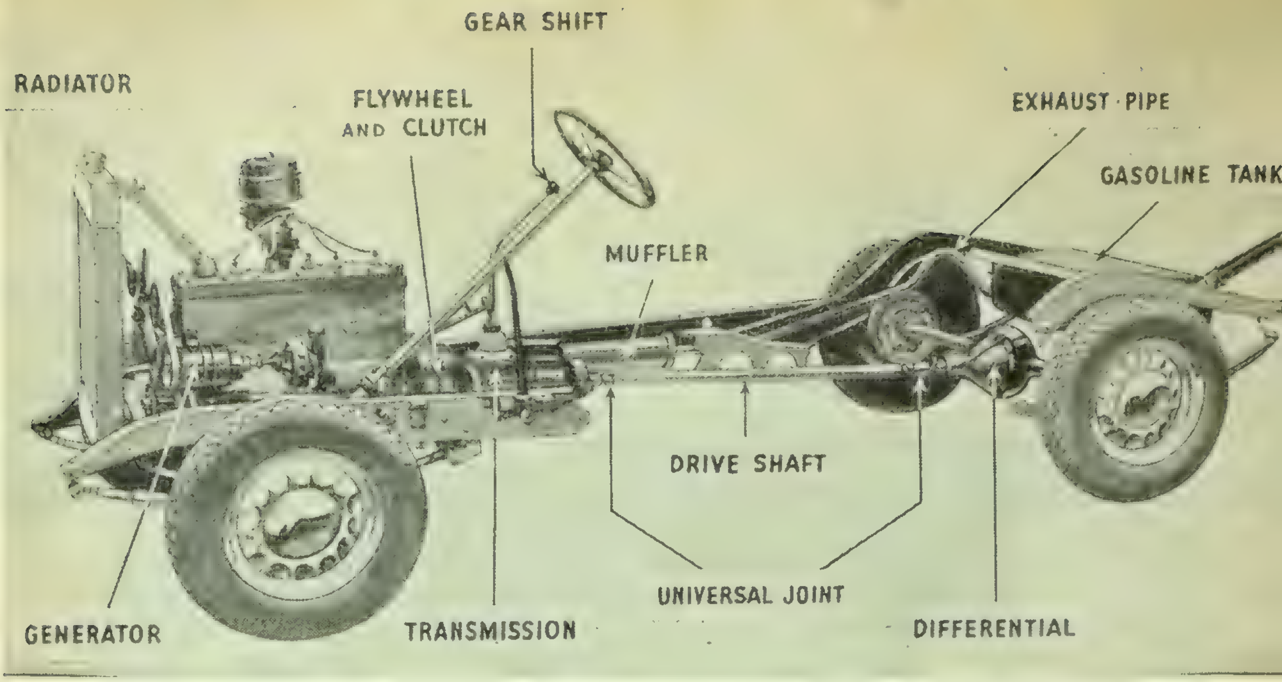


FIG. 489. The *chassis* of an automobile. The *universal joints* in the drive shaft are somewhat like the ball-and-socket joints in your body. A rigid drive shaft would break when the car bounced.

In order to keep the fire very hot so that there will be high steam pressure, there must be a strong draft through the fire box. The smokestack is too short to make a strong enough draft. (See page 114). This increased, or *forced*, draft is produced by leading the exhaust pipe from the engine into the smokestack. The rush of steam through the stack carries the burned gases out with great force, and fresh air enters the fire box through the draft openings.

HOW DOES A GASOLINE ENGINE RUN AN AUTOMOBILE? The use of a gasoline engine to run an automobile is different from the use of a steam engine in a locomotive. The force exerted by a gasoline engine depends upon its speed; the greater the speed of the engine, the greater the force delivered. Since much greater force is needed to set an object in motion than to keep it moving, it is clear that the engine itself must be running at high speed before the car can be started. Of course, it would be impossible to connect the engine to the driving wheels when it is going at high speed and the wheels are not moving. For this reason there must be some device to disconnect the engine from the wheels of the car. This device is known as the *clutch*. There must also be sets of gears and a shaft to transmit the force from the engine to the rear wheels. These are known as *transmission* gears (directly back of the clutch), the *drive shaft*, and *differential* gears (in the middle of the rear axle).

You know that when the engine of an automobile is started, the car is not set in motion. This means that the engine is not

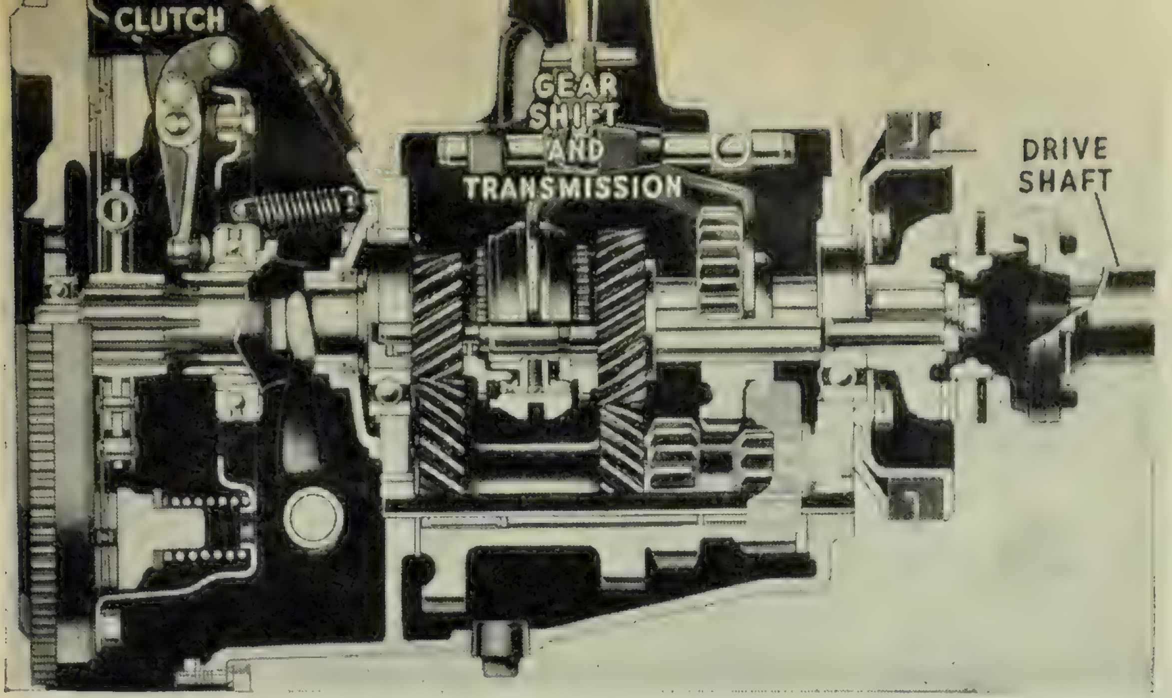


FIG. 490. A cutaway view of the clutch and the transmission gears of an automobile. The big gear at the extreme left is on the rim of the flywheel. It enmeshes with a smaller gear on the starting motor when you use the "starter." (Ford Motor Co. photo)

connected with the rear wheels. To start the car, the clutch pedal is pressed down, the gear-shift lever is pulled to the left and back, the clutch pedal is then slowly released, and the car moves forward in low gear. The clutch pedal is again pushed down, the gear-shift lever is moved to the right and forward, the clutch pedal is released, and the car is in second gear. A similar set of operations places the car in high gear. Some cars have a different shift from the one described, and some have automatic gear-shift devices. However, the same principle of operation holds true in all cases. Let us see the reasons for these operations.

We shall begin with the engine. Like the stationary gas engine the automobile engine has a flywheel which is rotating whenever the engine is operating. Back of the flywheel ("back" meaning toward the rear of the car) is the clutch. This disconnects the engine and the rear wheels, allowing the engine to run while the car is standing still. To show how the clutch works, mount two ordinary pie plates, each on the end of a shaft. Holding the shaft loosely in your hand, set one disc spinning. Start the other one by bringing it into contact with the first. This is the principle of the single-disc clutch used on many automobiles. One plate is fixed to the flywheel, the other to the transmission gears. Letting the two discs come together connects the flywheel with the transmission so that the flywheel causes the gears to turn around with it. We say that the clutch is "in." Now let us see how the transmission gears provide different car speeds.

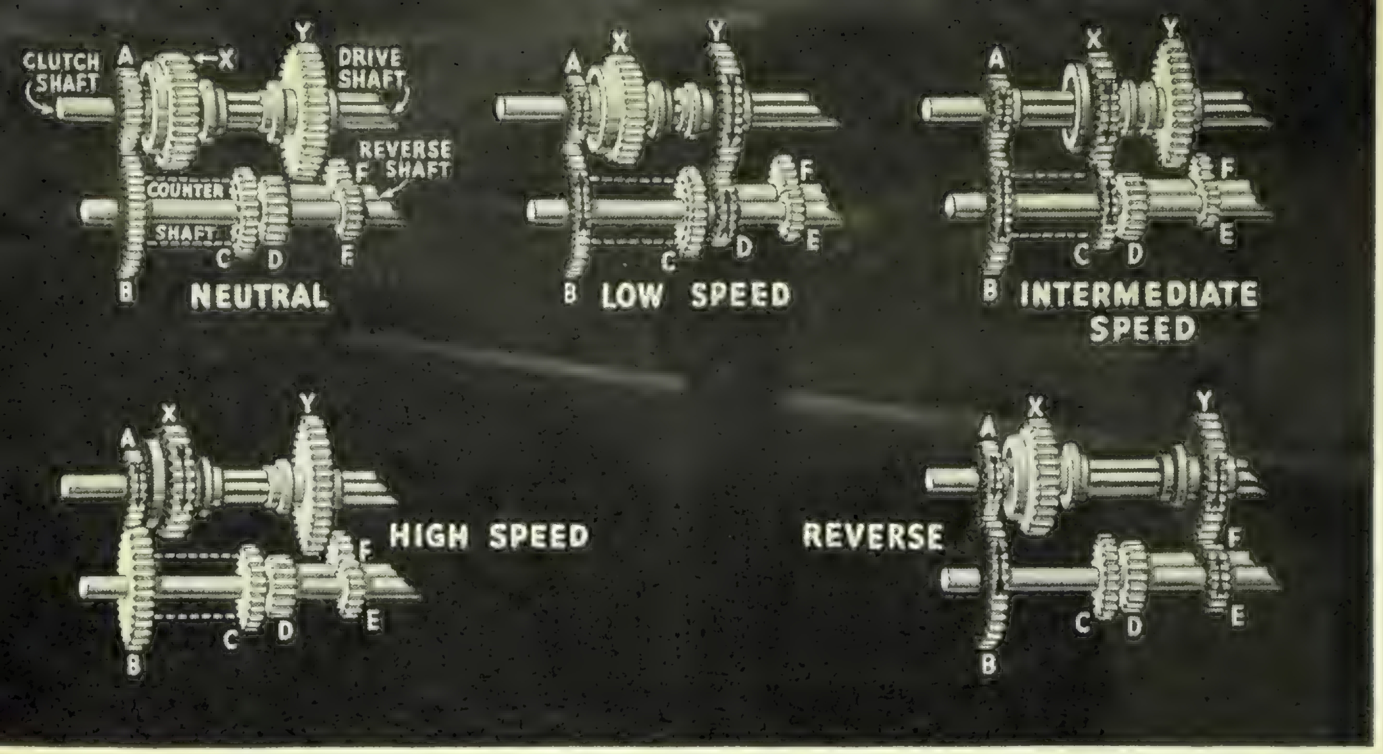


Fig. 491. See if you can explain these drawings of the gear shifts. The letters have been put on the gears to help you explain what happens.

If you will examine Figure 491, you will see the position of the gears when the car is in neutral, first speed (low), second speed (intermediate), high speed, and reverse. In neutral, gear A on the shaft connected with the clutch is *meshed* with a gear (B) on the countershaft. None of the gears on the countershaft, however, are meshed with gears on the *drive shaft*; thus, no power is transmitted to the rear wheels. The gears on the drive shaft are sliding gears and can be moved back and forth on the shaft by the *gear-shift* lever. When you shift into "low," you push down on the clutch pedal to disconnect the engine from the gears. Then with the gear-shift lever you slide gear Y so that it is meshed with gear D on the countershaft. The drive is therefore as follows: Gear A drives gear B, which turns the countershaft upon which is gear D. Gear D drives gear Y, which turns the drive shaft. If you examine the other parts of the figure, you will see what happens in intermediate, or second, speed. When the car is shifted into "high," gear X is pushed forward against gear A and locked with it. The clutch shaft and the drive shaft then rotate in the same direction and at the same speed as the crankshaft of the engine.

Perhaps you wonder why it is necessary to shift the gears and why the gears are of different sizes. You remember from your study of machines that you get greater force if you sacrifice speed. Let us see how this is applied in the automobile. When the car is in "low," gear D is much smaller than gear Y, which it drives. This means, of course, that the drive shaft will move much more

slowly than the countershaft or the crankshaft. It is therefore possible to exert a greater force on the drive shaft. In other words, this secures a mechanical advantage of force (page 391). You can see that gears X and C, which are enmeshed when the car is in "intermediate," are nearly the same size. This decreases the mechanical advantage but increases the speed. This is satisfactory because the car is now moving, and not so much force is needed to keep the car moving as to put it in motion.

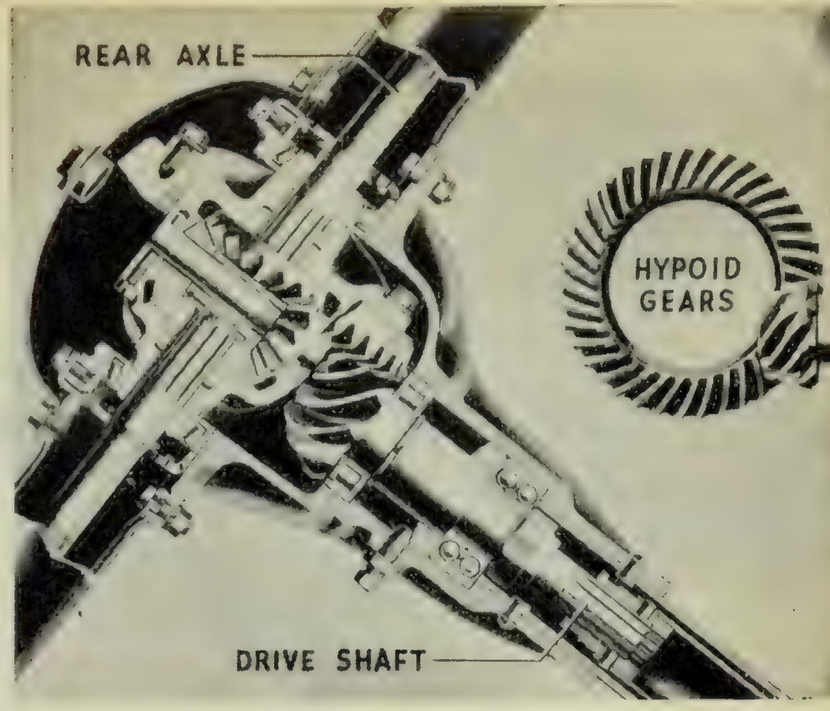

FIG. 492. Cutaway view of an automobile differential. Find out what is meant by *hypoid* gears. (General Motors photo)

The power of the engine is transmitted to the rear wheels by the drive shaft. Since the drive shaft turns in a direction different from that of the rear wheels, another system of gears is necessary to change the direction of the motion. This change of direction is accomplished by the differential, which is in the middle of the rear axle (Figures 489 and 492). The differential also permits one rear wheel to turn faster than the other, which is necessary when the car is going around a corner. Why?

*Self-Testing Exercises.* 1. Why does an automobile have a clutch?

2. Why are there several sets of gears in the transmission?

3. An automobile is standing still with the engine running. Tell, step by step, what happens until the rear wheels begin to turn.

4. When an automobile is moving along a level road, what would happen if someone held the clutch pedal down? Explain.

*Problems to Solve.* 1. When a car is standing still, shifting into gear without throwing the clutch out may stop the engine or break something. Explain why.

2. If an automobile were driven by a steam engine, what parts of the transmission system could be eliminated?

3. What changes have been made in the transmission systems of the newest automobiles? Talk to salesmen and read recent science magazines and automobile advertising booklets.

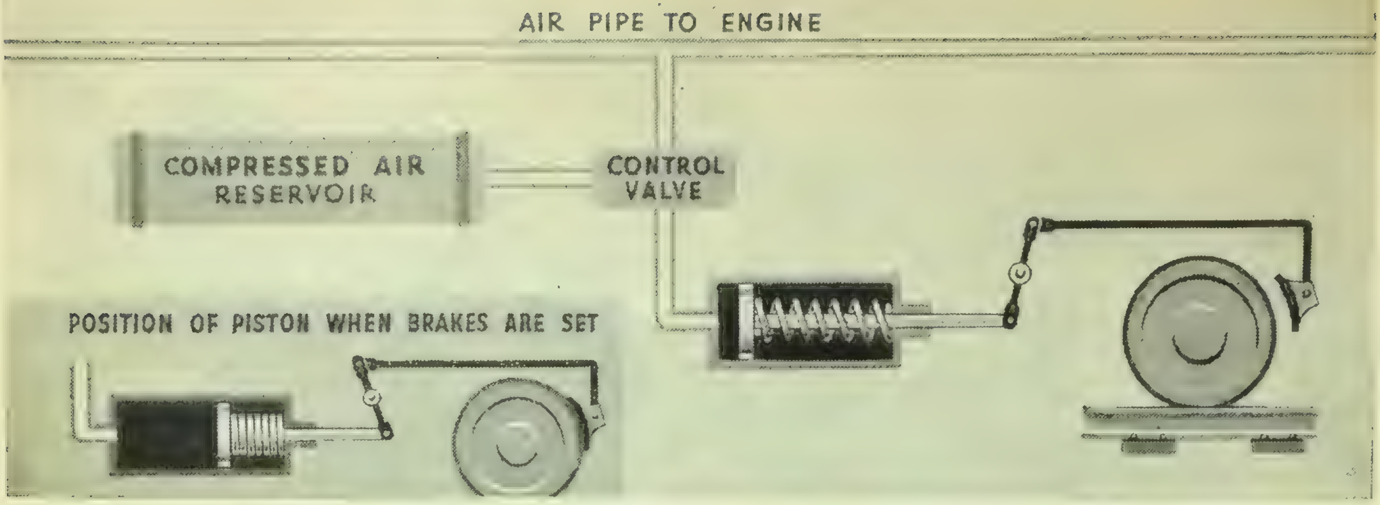


FIG. 493. How the compressed-air brakes on a train operate. Study the positions of the piston in the two drawings of it.

HOW DO WE STOP LAND VEHICLES? Almost as important as the problem of making a vehicle go is the problem of stopping it. Of course, you begin to stop a train or an automobile when you shut off the power. But without some kind of *braking system*, no land vehicle would be either safe or convenient to use.

Perhaps the most useful compressed-air device is the *air-brake* used to stop trolley cars, trains, and heavy automobile buses and trucks (Figure 493). On trains a compression pump on the engine forces air into a large tank or reservoir, keeping the air at a pressure of about seventy-five pounds per square inch. This reservoir is connected by means of pipes and by air-tight couplings between cars to a smaller reservoir and the brakes under each car. While the pressure in the engine reservoir is at seventy-five pounds per square inch, the control valve is in such position that the two reservoirs are connected by the air-pipe.

If the engineer opens the valve on the air-pipe connecting the engine reservoir to the car reservoir, air escapes, and the pressure in the air-pipe becomes less. Then the pressure in the car reservoir turns the control valve in such a way that the compressed air enters the brake cylinder and forces the piston to the right with great force. The piston rod operates the brake levers and sets the *brake shoes* against the wheels. This also happens if the couplings between cars come apart or the pipe line is broken.

When the air is again turned on from the engine reservoir, the control valve turns so that the car reservoir is connected with the air-pipe, and the compressed air in the brake cylinder can escape. The heavy spring in the brake cylinder now pushes the piston rod back and releases the brakes. You have probably heard this escaping air just after a train has stopped.

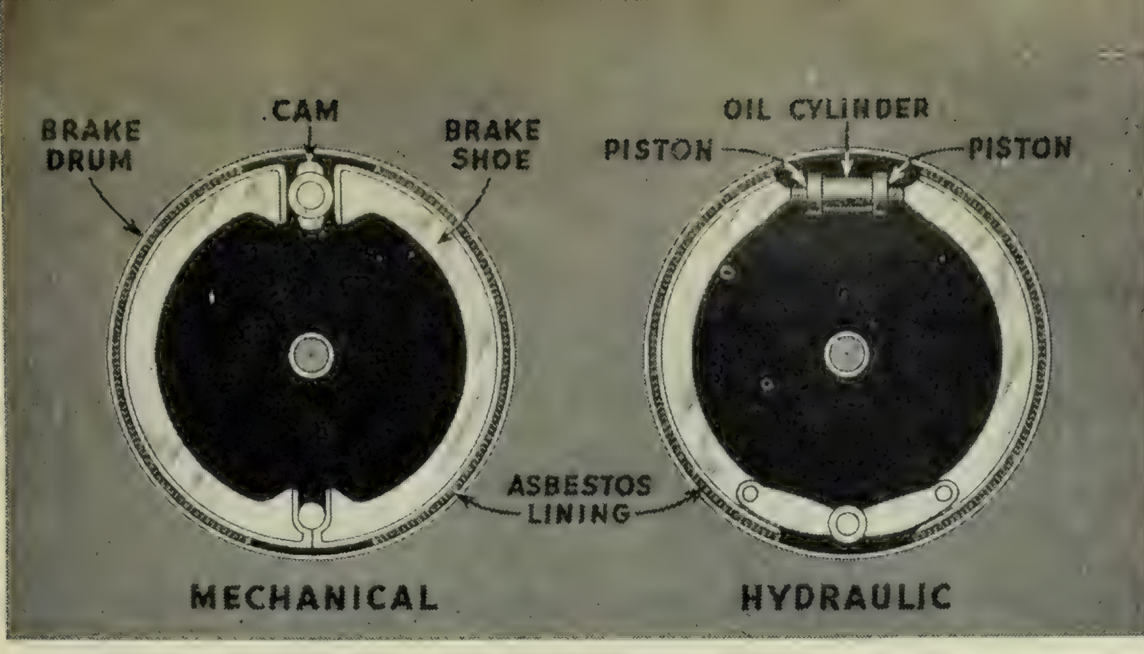


FIG. 494. The drawing at the left shows how a mechanical brake is constructed. An hydraulic brake is shown at the right.

To slow down and to stop automobiles, two types of braking systems are used, *mechanical* and *hydraulic*. In both types a steel *drum* is attached to the wheels. In mechanical brakes a system of levers and rods connects the brake pedal in front of the driver's seat with the *cam* inside the drum. When the brake pedal is pushed down, the cam turns and pushes against the brake-shoe. The brake-shoe pushes against the *brake lining*, which is made of asbestos. The friction of the rough asbestos lining against the brake drum slows the wheel down. In hydraulic brakes a system of tubes containing oil under pressure is connected with a cylinder inside the brake drum. When the brake pedal is pushed down, the oil is put under more pressure and two pistons in the cylinder are forced out against the brake-shoe.

In order to prevent a car from swerving or skidding when the brakes are put on suddenly, it is absolutely necessary that equal pressure be applied to each of the four brakes. In other words, the brakes should be *equalized*. Careful drivers have their brakes checked and equalized frequently. Some cities now require that this be done. When you are riding in an automobile, your life depends upon your brakes. Even when you are walking, your life may depend on the brakes in someone else's car.

When you wish to slow down a car, it is a good plan to take your foot off the accelerator pedal but leave the clutch engaged. Your car will then be trying to go faster than your engine. The wheels of your car will be turning the engine, and the engine will act as a brake. In going down mountains or other long hills the engine can be shifted into second gear, or even into low gear if the grade is very steep. In this way the car has to make the

engine go much faster, which takes more force. Therefore the car is held back. This saves the linings of the brakes, which may otherwise become so hot that they catch fire.

*Self-Testing Exercises.* 1. Explain briefly how air brakes work to stop a long train.

2. A train comes to an abrupt stop when it happens to break apart. Explain why the air-brakes are set when the train breaks apart.

3. When you push down on a brake pedal, the force of your muscles is transferred to other places. (*a*) To what places is it transferred? (*b*) How is it transferred in mechanical brakes? (*c*) How is it transferred in hydraulic brakes?

*Problems to Solve.* 1. The energy of compressed air is greater than the energy of an equal amount of ordinary air. Where does the compressed air obtain this additional energy?

2. Why is it a good thing for each car of a train to have its own pressure tank to operate the brakes?

3. From a garage get as many old brake parts as you can. Bring them to class for study.

4. What advantages do hydraulic brakes have over mechanical brakes?

5. How is the force of your foot increased by the braking system of a car?

## 2. How are boats and ships operated?

WHY CAN SHIPS FLOAT ON WATER? A submarine is a strange boat. Sometimes it travels along the top of the water like any other boat. At other times all openings are closed, and it sinks beneath the surface. When the captain gives the word, it rises to the surface again. The submarine can do these things because the men who made it and the men who run it understand one of the laws of science called *Archimedes' Principle.* Archimedes was a famous Greek scientist who lived about 200 years before Christ. To help you understand this principle, you can do two experiments almost exactly like the ones that Archimedes did.

*Experiment 108.* HOW DOES THE WEIGHT OF A STONE IN AIR COMPARE WITH ITS WEIGHT IN WATER? (*a*) Tie a thread or string about a stone of convenient size. Hang the stone on a spring balance that is marked in grams instead of ounces. Find the weight of the stone in air.

FIG. 495. Apparatus for Experiment 108

*b*) Then lower the stone into a jar or pan of water so that it is entirely covered but does not touch the jar (Figure 495). Does it weigh the same as it did in air? What does its weight seem to be? How many grams did the stone seem to lose?

*Experiment* 109. HOW DOES THE WEIGHT LOST BY A STONE IN WATER COMPARE WITH THE WEIGHT OF THE WATER IT DISPLACES? (*a*) Fill a large graduated cylinder (Figure 497) half full of water and notice carefully the number of cubic centimetres of water you have. (Be sure to use the mark that is even with the level part of the water, not the one at the curved-up edge.) Lower the stone used in Experiment 132 into the water in the cylinder. Read the number of cubic centimetres of space filled by both the water and the stone. Find out how many cubic centimetres of space the stone fills.

*b*) One cubic centimetre of water weighs one gram. How many grams of water were pushed aside, or displaced, by the stone? How many grams of weight did the stone lose when it was in the water? How do the two figures compare?

*c*) Repeat Experiments 108 and 109 with two or three other stones or convenient objects that will neither float nor absorb moisture. What is your answer to the problem of this experiment?

Perhaps you have never tried to lift a large stone out of a pond of water and noticed how its weight seemed to change when it came up into the air. The first of your experiments shows that a

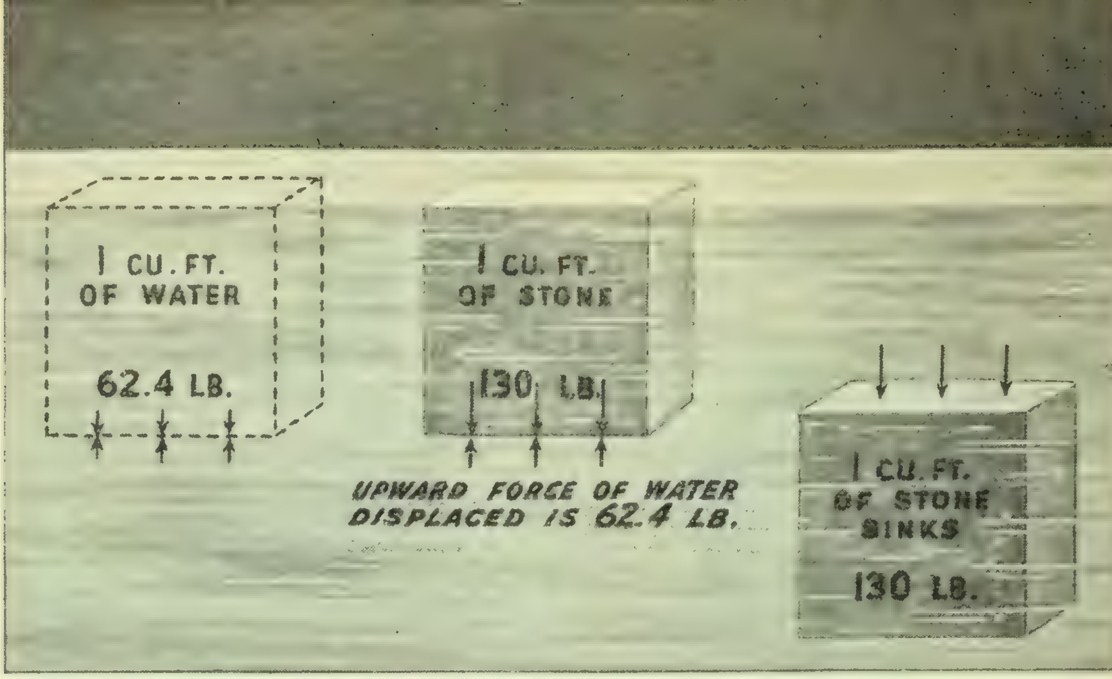


FIG. 496. If a cubic foot of stone weighing 130 pounds is held under the surface of the water, the upward force of the water will be less than the downward pull of gravity. How much less? Because gravity is pulling downward harder than the water is pushing upward, the stone will sink.

stone really does seem lighter in water than in air. Can you tell why this is true? If your measurements in Experiments 108 and 109 were carefully made, you probably found that the weight lost by your stone was, as nearly as you could tell, equal to the weight of the water it pushed aside when you lowered it into the cylinder. In other words, the water lifts the stone with a force that is just equal to the weight of the water which fills the place where the stone was. Archimedes' Principle is stated in this way: *Any object placed in a fluid is buoyed up (pushed upward) by a force equal to the weight of the fluid that it displaces.* (A *fluid* is a substance that will flow. Water and air are both fluids.)

Exact experiments show that Archimedes' Principle is true. But why is it true? How can water lift up a stone that is placed in it? In the first place, we know that any liquid pushes in all directions; that is, when the stone was under water, the water was pushing up on the bottom, down on the top, and against the sides. In the second place, the deeper anything goes into a liquid, the greater the pressure becomes. The bottom of the stone was farther down in the liquid than the top. Thus the water pressed up harder on the bottom than it pushed down on the top. The extra force on the bottom tended to push the stone up and make it easier to lift. Careful measurements show that the extra force that tends to overcome the gravity of the stone is just equal to the weight of the water that would go in the space the stone occupies.

To see clearly what this principle means, imagine that you have

a block of stone which contains exactly one cubic foot. The cubic foot of stone weighs 130 pounds. Water weighs 62.4 pounds per cubic foot. Now you lower the stone into water. The stone pushes aside one cubic foot of water. It seems to get 62.4 pounds lighter. Your stone would seem to weigh only 67.6 pounds (130 pounds minus 62.4 pounds). Gravity is pulling down with a force of 130 pounds on the stone. But at the same time gravity is making the water push up on the bottom of the stone 62.4 pounds harder than it is pushing on the top of the stone. The pull of gravity on the stone wins, and the stone sinks in the water. In the same way any object will sink in a liquid if it weighs more than the liquid it displaces.

Do you see, now, that when you throw any object into the water, there is a "contest" between the weight of the liquid and the weight of the object. If the contest goes one way, the object floats. If it goes the other way, the object sinks. Let us see how this contest works.

*Experiment 110.* HOW DOES THE WEIGHT OF A FLOATING OBJECT COMPARE WITH THE WEIGHT OF THE WATER IT DISPLACES? (*a*) Put just enough sand in a test-tube to make it float upright in water. Dry the tube carefully and find the weight of the tube and the sand in grams. Fill a 100-cubic-centimetre graduated cylinder about half full of water and record the exact number of cubic centimetres of water it contains. Lower the weighted tube carefully into the water in the graduated cylinder and notice what happens to the water.

How many cubic centimetres does the water rise? Compare the weight of this number of cubic centimetres of water with the weight of the tube and the sand before they were placed in the water.

*b*) If you wish to do so, drop a five-gram weight into the test-tube and measure the rise of the water in the tube. Continue to add weights and measure the displacement until the water reaches almost to the top of the test-tube.

FIG. 497

Blocks of wood, tin cans, stoppered glass bottles, and steel ships all float in water. Some may even float with the larger part of them above the surface of the water. Can you explain why they all float, even though pieces of steel, glass, and tin will sink?


FIG. 498. If a cubic foot of wood weighing 31 pounds is held under the surface of the water, the upward force of the water will be greater than the downward pull of gravity. How much greater? Because the water is pushing up on the block harder than gravity is pulling it down, the block will float if it is released.

Let us begin with the block of wood. A cubic foot of pine wood weighs only about one-half as much as a cubic foot of water; that is, it weighs about 31 pounds. When a cubic foot of wood is placed under water, there is a push of water on the bottom of the block. This push that lifts the block against gravity is 62.4 pounds. Gravity pulls down on the block with a force of about 31 pounds. The water wins the "push of war," and the block must go upward until it stands above the surface of the water and displaces only about one-half a cubic foot of water, because one-half a cubic foot of water weighs about 31 pounds. Any material that weighs less per cubic foot than a liquid will float in the liquid.

But what about iron and glass? They are denser than water, yet they can be made to float. (See page 57.) You probably know that the cans, bottles, and steel ships that float are all "hollow." Since they contain air spaces, their average weight per cubic foot is less than the weight of a cubic foot of water. This means that a part of a ship, for example, will still be above the water after it has displaced its own weight of water.

Now let us return to the problem of the submarine. Why does it sometimes float on the water and sometimes sink below the surface? You know that when the submarine is floating on the water, it must be less dense than water. It is less dense because of its hollow steel body. However, the boat is made with several "diving tanks" in it. These are compartments into which the water may be allowed to run and from which it can be pumped

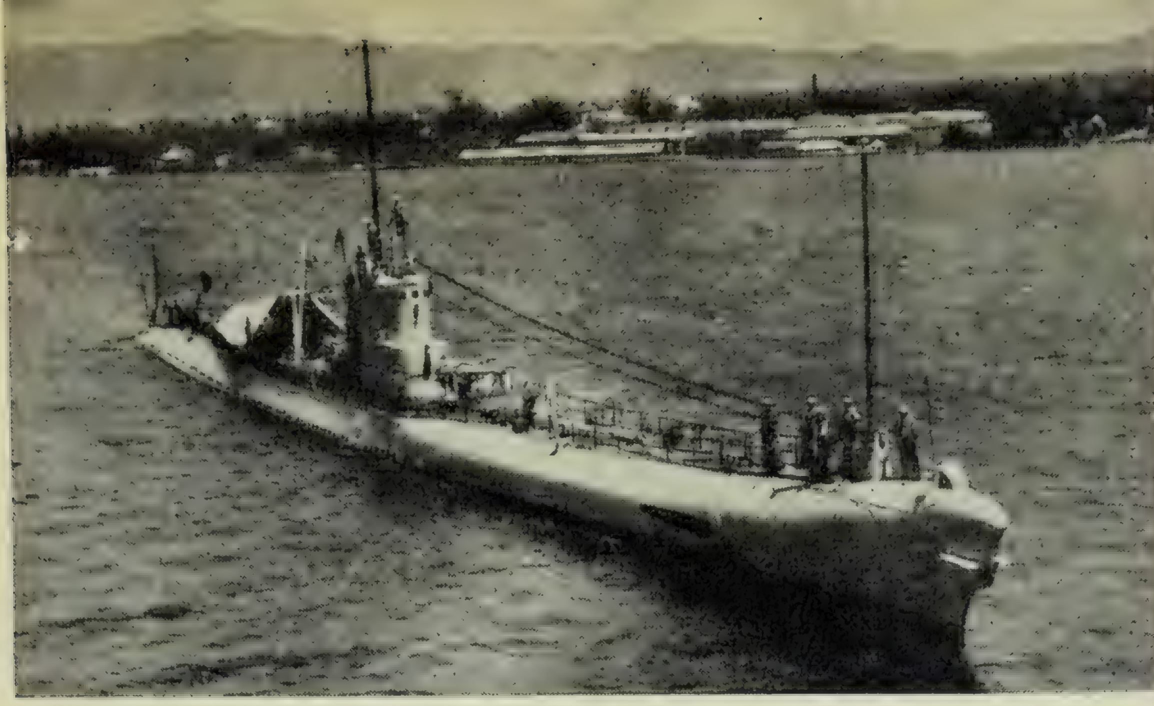

FIG. 499. Modern submarines may be over 350 feet long. They can travel 35 miles per hour on the surface and 15 miles per hour when they are submerged.

out. When the command to dive is given, water is allowed to enter the diving tanks until the boat becomes just about the same weight as the water it displaces when it sinks below the surface. The submarine can then move through the water at any depth down to about two hundred feet.

Special diving rudders are used to guide the boat upward or downward as it moves through the water. When the captain wishes to have the boat come to the surface, air is pumped into the diving tanks. This air pushes the water out, the submarine becomes lighter, and the water pushing against its lower side sends it to the surface.

*Self-Testing Exercises.* 1. What is Archimedes' Principle?

2. When an object floats on water, what do you know about the density of the object?

3. Steel sinks in water, but steel ships float. Tell why.

4. Many life-boats on ocean ships have air-tight hollow spaces in their sides. How does this kind of structure make the life-boats safer?

5. (*a*) Explain how a submarine uses Archimedes' Principle. (*b*) What is done to bring a submarine to the top of the water? Why does this plan work?

*Problems to Solve.* 1. Mercury weighs 849 pounds per cubic foot; gold, 1194 pounds; iron, 487 pounds; platinum, 1204 pounds; and silver, 655 pounds. Which metals would float in mercury and which will sink?

2. Does ice float or sink in water? What does this tell you about the density of ice as compared with that of water?

FIG. 500. Screw propellers were first used on ocean-going ships in 1839. The first steamship to cross the Atlantic under steam was a Dutch "side-wheeler"; the second was the *Royal William*, built in Quebec by Samuel Cunard. In 1840 Cunard established the first transatlantic "line" of steamers.

3. (*a*) If a ton of goods is loaded on a ship, how much water will be pushed aside by the settling of the ship? (*b*) How many cubic feet of water will be pushed aside? (1 cu. ft. of water weighs 62.4 lbs.)

4. A stone weighs 135 pounds in air but 73 pounds in water. How many pounds of water does the stone displace? How many cubic feet?

5. If your body just floats in fresh water, about what is its average density? The volume of your body is how many cubic feet?

6. Many people think that when a ship sinks, it goes only part way to the bottom of the ocean. Is this true or not? How do you know?

7. How could you use the test-tube weighted with sand (Experiment 110) to tell whether a liquid is more or less dense than water?

HOW ARE SHIPS PROPELLED? Two methods of propelling steamships are in common use today. The older method is that of the large revolving wheel fitted with broad blades, or paddles. These may be located one on each side of the boat, or one may be used at the stern. Water is a material; therefore it offers resistance to the passing of the blades through it. As the wheel turns and the blades strike the water, the boat is pushed forward because the blades push against the water. The modern propeller is shaped like the blades of an electric fan (Figure 500).

Ships may be driven by one, two, or three screws, or propellers. If they are driven by one screw, the shaft from the engine which drives the screw passes through a hole in the stern in front of the rudder. If two screws are used, one is placed on each side at the stern. If three screws are used, one is in the middle of the stern,

and one is placed on each side of the stern. A three-screw ship has several advantages over a one-screw ship. In the first place, in case one screw is disabled, or if the engine which drives it breaks down, the ship can still be propelled by the other screws. It is also possible to drive the screws at different speeds so that the ship can be steered without a rudder. This is especially helpful in turning the ship.

How are ships kept going in the right direction? When you travel on land, it is generally easy to find your way. Roads are laid out in more or less regular lines, and the highways are so well marked that it is hardly necessary even to know the directions. But on the ocean travel is a different matter. When land is out of sight, the only natural direction-finders are the sun by day and the stars by night. Navigators need to know, however, their exact position so that they may be sure of travelling toward their destination in a reasonably direct route and so that they may avoid shallow water and rocks.

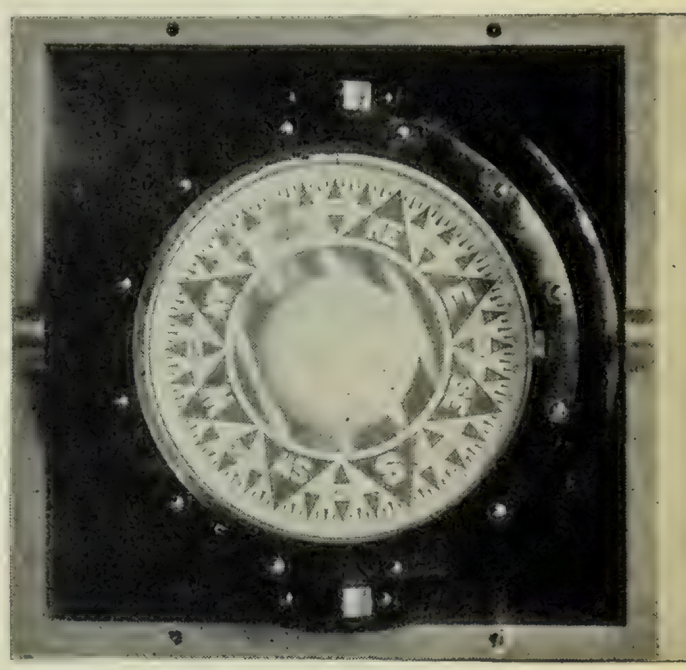

Fig. 501. A ship's compass

No one knows exactly when or where the *compass* (Figure 501) originated, but history tells us that it was in use during the twelfth century. The compass *dial*, or *card*, was divided into thirty-two parts and marked as it is today before the close of the fourteenth century. The four *cardinal points*, north, east, south, and west, were of course used by man thousands of years ago. You have probably played with small compasses such as Boy Scouts carry to find their way in the woods. You may even have seen the large ones used by surveyors and sailors. All these compasses are only magnets fixed so that they can swing around in a circle.

Do you know how to use a compass to tell directions? This is how you do it: Put the compass on something level and see that there is no iron or steel near it. Let the needle stop swinging. Turn the case of the compass around until the N on the case is at

the tip of the needle that points north. This end of the needle is usually shaped like an arrow or marked in some other way. East and south and west will then be shown by marks on the compass card.

If a piece of steel is magnetized and mounted in such a way that it may move freely, one end of it will point in a northerly direction. This end is called the *north-seeking* pole of the compass needle. Without doubt the ancients believed that the compass pointed to true north, but in most places on the earth's surface it really points several degrees to the right or left of true north. Experiment also showed that as the compass was carried north or south on the surface of the earth, the needle tilted up or down. This led scientists to believe that the earth possesses *magnetic poles.*

In the year 1831 Sir James Ross located the north magnetic pole of the earth. At that point the north-seeking end of a special kind of compass called a *dipping needle* points straight down. This location was found to be about 1200 miles from the geographical north pole. Because of the difference in the positions of the magnetic and the geographic poles, the compass needle will not point true north. Since 1831 maps have been constructed to show the difference between true north and the magnetic north (Figure 502) and between true south and the magnetic south. This difference is called the *magnetic declination.* Strangely enough, the magnetic poles of the earth slowly change their positions. The constant moving of the magnetic poles makes it necessary for governments to make new magnetic maps of the earth from time to time.

*Self-Testing Exercises.* 1. What is a compass?

2. If you were lost in the woods on a cloudy day and had a compass, how would you use the compass in order to go straight west?

3. How does a dipping needle show where the magnetic poles of the earth are?

4. Tell why a compass points north and south.

5. Why doesn't the compass always point to the true north?

6. Find where you live on the map in Figure 502. Does a compass point north, or east of north, or west of north where you live? About how much?


FIG. 502. Magnetic declination in North America. Only on the line marked "No Variation" does the compass needle point true north.

7. If a compass always pointed true north, no matter where it was located, what would this tell you about the location of the north magnetic pole and the north geographic pole?

*Problems to Solve.* 1. Is the north-seeking pole of a magnet like the north magnetic pole of the earth? How do you know?

2. Would you expect a compass to point in the right direction if you were near a large deposit of iron ore? Tell why or why not.

3. If you were lost in the woods on a cloudy day, but had a piece of magnetized clock spring and a thread with you, how could you tell directions?

4. See how many reasons you can give for believing that the earth is really a large magnet.

5. When a compass was placed on a certain table, the compass needle pointed to the east instead of to the north. The table was turned around, and the needle then pointed to the west. Explain.

6. If a piece of steel were hanging by the middle, how could you find whether it was a magnet?

7. If you should look up the locations of the magnetic poles of the earth in several books published in different years, you would

find that no two of them gave the same locations for the magnetic poles. Would this mean that the books were wrong when they were written? Explain.

8. Do you think the captain of a ship should pay attention to the number of degrees his compass varies from true north? Why?

9. Make a *dipping needle*. Get a long steel knitting needle and a darning needle that are not magnetized. Push the knitting needle through a cork in one direction and the darning needle through the same cork at right angles to the knitting needle. Balance the apparatus on two smooth jars or bottles, as shown in Figure 503, by pushing the knitting needle through the cork until it stands exactly level. Have the knitting needle pointing north and south.

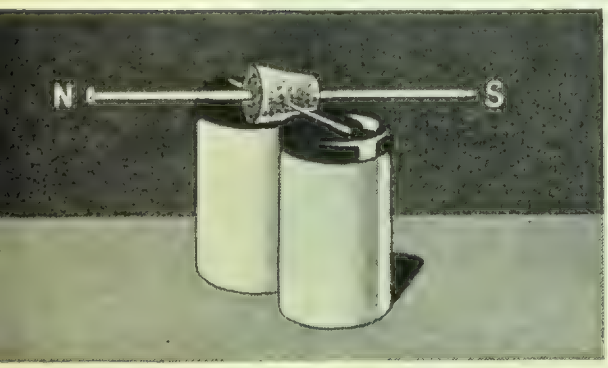


FIG. 503

Lift the needles and cork from the jars; be careful not to change the position of the needles in the cork. Magnetize the knitting needle strongly by stroking it many times with a strong magnet. Stroke both ends, but be careful to stroke both in the same direction with the same pole of the magnet. Put the apparatus back on the jars just as it was before. Is it still balanced? Why does it act as it does?

HOW DOES A NAVIGATOR FIND THE LOCATION OF HIS SHIP? The compass is very useful to steer by, but it does not tell you how far you have travelled or where you are located at any particular time; so, other instruments have been invented which, used together with maps, give this information. Columbus had very little idea of the distance he travelled, because he had no way of measuring it.

The first device for measuring distance travelled on the water appeared early in the seventeenth century. This instrument was called the *log*. It consisted of a stick of wood attached to a rope. On the rope were knots placed at regular intervals of about fifty feet. When navigators wished to find out how fast the ship was going, they threw the log overboard, and a sailor counted the number of knots that slipped through his hand in a given time as measured by a half-minute sand glass. The number of knots that passed through the sailor's hand in the half minute represented the number of *nautical* miles made an hour by the boat. The

nautical mile is 1.15 times as long as the ordinary mile. The word *knot* is generally used by sailors to mean the nautical mile.

The log used now consists of a steel torpedo-shaped rotator attached by a cable to a speedometer on the ship's rail (Figure 504). The speed at which the rotator turns depends upon the speed of the ship. The small hand on the recording instrument indicates the rate of travel. The log, when used with the compass, furnishes a rough estimate of the ship's position, but this method is always checked by means of other, more accurate instruments.

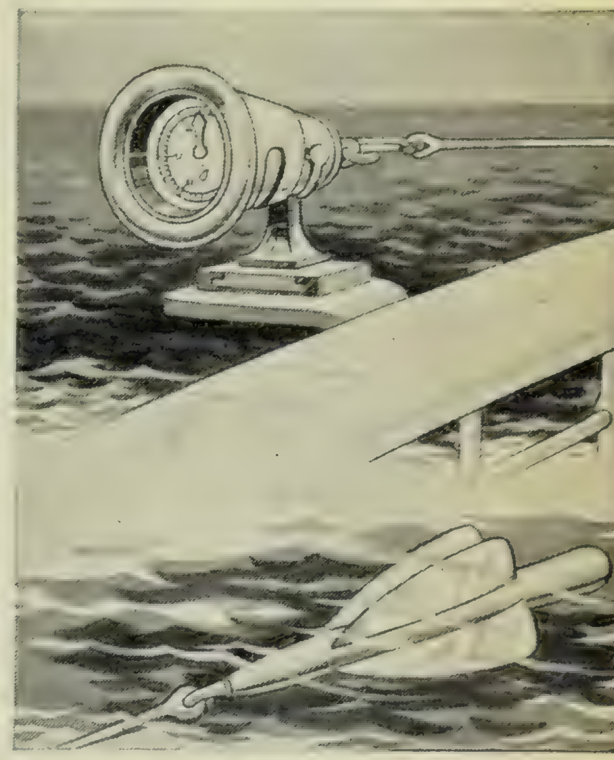

FIG. 504. A ship's log

In order to obtain the exact position of a ship it is necessary to determine its *latitude* and *longitude*. The latitude gives the distance north or south of the equator, and the longitude gives the distance east or west of the prime meridian at Greenwich. This distance is measured in terms of degrees (°), minutes (′), and seconds (″). By means of a map navigators may easily determine the latitude and longitude of a place. In the same way the navigator of the ship, having found the latitude and longitude, can locate his exact position by means of the map.

Longitude is determined by means of a *chronometer* and a *sextant*. The chronometer is simply a very accurate clock. Ships usually carry two chronometers. One is set according to Greenwich time (page 438), and the other shows ship time, that is, actual time of day on board the ship. The sextant is an instrument used to measure the angle of the sun or some other heavenly body with the horizon line (Figure 505). Just before noon, according to ship time, one of the ship's officers begins his observation of the sun. The handle for the right hand is held in a vertical position, and the horizon line is sighted through the telescope. Then the movable arm is adjusted until the light from the sun is reflected by the upper mirror to the horizon line in the horizon mirror. When the sun has reached its highest point, it will be

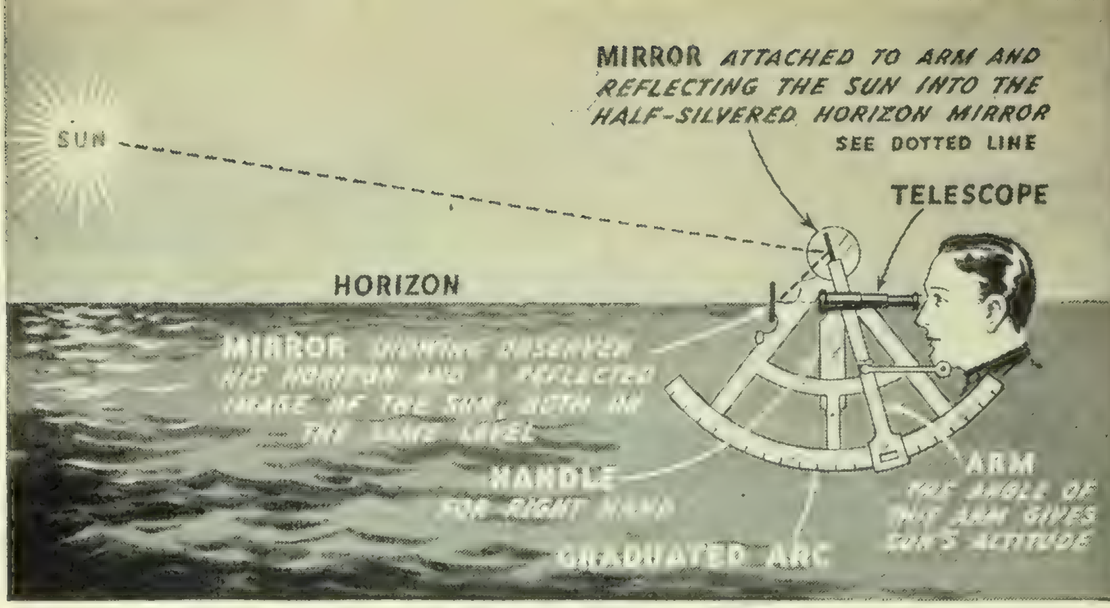


FIG. 505. How a sextant is used to find the latitude

exactly 12 noon. Comparison is then made between ship time and Greenwich time. Suppose that Greenwich time is 11 A.M. and the ship time is 12 noon. The difference in time is one hour. This means that the ship is at 15° east longitude. (See page 438.)

The latitude is determined by means of the sextant. You know that on September 23 and March 21 the sun is directly over the equator at noon. (See pages 436-437.) It therefore makes an angle of 90° with the horizontal (Figure 506). If you were located at the North Pole on these days, the sun's rays would be horizontal; that is, you would see the sun by sighting directly along the horizon. If you were halfway between the equator and the North Pole, that is, 45° latitude, the angle of the sun's rays would make an angle of 45° with the horizontal (Figure 506). Therefore on these two days the latitude may be determined by simply measuring the angle of the sun's rays with the horizontal at 12 noon and subtracting it from 90°.

Since, however, the sun is not always directly over the equator, it is necessary to correct the angle according to the time of year. Navigators carry charts which give the correction for each day of the year. In finding the latitude, therefore, the angle of the sun with the horizon at 12 noon is determined with the sextant. This is the angle between the vertical arm and the movable arm when the sextant is correctly sighted at noon. This angle is then corrected according to the time of year. When the corrected angle is obtained, it is only necessary to look in the tables to find the correct latitude. At night, when the sun is not visible, the navigator obtains his position from the stars. The radio and the *radio compass* have also made it possible for the ship captain to work out his position by radio or to obtain it from radio stations.

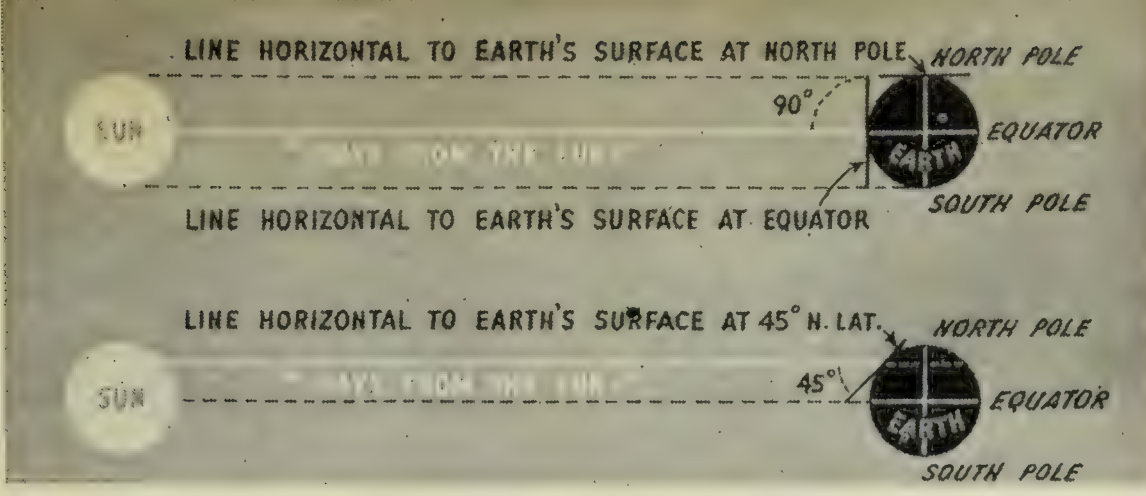


FIG. 506. How latitude is determined at two different places when the sun is directly over the equator

*Self-Testing Exercises.* 1. How do propellers push a boat through the water?

2. What is the use of a log on a ship? How does a modern log work?

3. What is a knot as the word is used by sailors? How did the word get this meaning?

4. What is latitude? Longitude?

5. (*a*) What angle does a navigator measure by using a sextant? (*b*) At what time of day does he take this measurement?

6. (*a*) How does a navigator tell when it is exactly 12 o'clock noon where he is? (*b*) How can he calculate his longitude from the time?

7. A ship captain made the following observations of his position on the twenty-third of September: ship time, 12 noon; Greenwich time, 9 A.M.; position of sun at noon, 22°. What were the latitude and longitude of the ship? (See Figure 506.)

8. Why does a navigator need charts to find his latitude?

## ¶ 3. How are balloons and dirigibles operated?

WHY DO BALLOONS RISE IN THE AIR? Have you ever seen a great passenger balloon floating in the air? The huge cigar-shaped balloons, called dirigibles, are built about a framework of aluminum alloy. Within the framework are large silk and rubber bags that are filled with a gas. Inside the balloon are also fuel tanks, rooms for the crew and passengers, and passageways from one part to another. Suspended on the outside are several motors with propellers to drive the balloon through the air. The great airship *Hindenburg*, which made many trips across the Atlantic Ocean before it burned in 1937, was more than 800 feet long. With crew and equipment it weighed 430,000 pounds, and it carried a load of 42,000 pounds. Yet this great mass of material floated in the air almost as easily as the toy balloons you buy at the circus. How was this possible?

In Unit 2 you learned that air has weight and you know that, like water, it is a fluid. Any object in the air must behave according to Archimedes' Principle. That is, it will be pushed upward by a force equal to the weight of the air that it displaces. This is true because the air-pressure on the bottom of the object is greater than that on the top (page 319). We do not often notice this lifting force of air, because the density of air is much less than that of water. A cubic foot of water weighs 62.4 pounds, while a cubic foot of air weighs approximately .08 of a pound. (The weight of air, of course, varies with the temperature and the pressure.) But we do notice that air can lift things when we fill a toy balloon with a gas that is lighter than air.

*Experiment 111.* WHAT KINDS OF MATERIALS MUST BE USED TO INFLATE BALLOONS? (*a*) Make some soapy water by dissolving soap in warm water and adding a little glycerine. Make a large soap bubble and shake it off the pipe. Does it rise or sink?

*b*) Attach a soap-bubble pipe to the gas jet by a rubber tube. Dip the bowl of the pipe (mouth downward) in the soapy water and turn the gas on slowly. When the soap bubble gets to be about four inches in diameter, shake it off. Does the bubble rise or fall? The weight of a cubic foot of illuminating gas is about .04 pound. Explain why the bubble falls when filled with air from your lungs but rises when filled with gas.

*c*) Generate a gallon bottle of hydrogen. To do this, place about 10 grams of zinc in the bottle and add 20 cubic centimetres of hydrochloric acid. Place the stopper in the bottle, but do not connect the rubber tube with the faucet. After a few minutes connect the tube which goes to the bottom of the bottle to the faucet, and connect the other tube to a rubber balloon. When the faucet is opened, the water will force the hydrogen out of the bottle into the balloon. As soon as the balloon is completely inflated, pinch the end of it and tie it securely. Take it outdoors and see how high it goes.

When a balloon is filled with a gas that is less dense than air, the air around the balloon pushes upward on the balloon harder than the balloon with the gas inside it is pulled downward by gravity. Thus the extra upward force of the air on the bottom lifts the balloon. Toy balloons that rise in the air are usually filled with hydrogen. Many large balloons also are filled with hydrogen. One thousand cubic feet of hydrogen weigh about

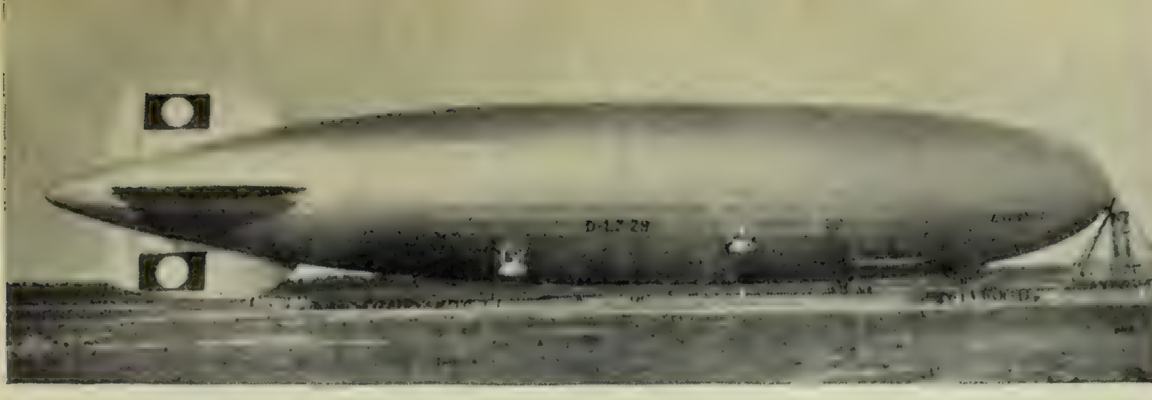

FIG. 507. This dirigible, tied to its mooring mast, is over 800 feet long. The white spots on the side are cabins that house two of its four powerful motors. (Acme photo)

5.6 pounds, but 1000 cubic feet of air at the surface of the earth weigh about 87.9 pounds. From these facts you can see that each 1000 cubic feet of hydrogen in a balloon on the ground will be pushed upward by the air around the balloon with a force of 82.3 pounds (87.9 lb. – 5.6 lb.). Thus, with a balloon holding 1000 cubic feet of hydrogen, the air will lift 70 pounds of rubber and cloth and also a load of twelve pounds.

The gas-bags of the *Hindenburg* displaced more than 7,000,000 cubic feet of air. This much air weighs about 507,200 pounds. The hydrogen that filled the balloon weighed about 35,200 pounds. The air on the outside of the gas-bags thus pushed up on them with a force that was 472,000 pounds more than the weight of the gas inside. Since the great balloon itself with all its equipment and with its crew weighed about 430,000 pounds, it could still carry 42,000 pounds in passengers and goods.

However, a balloon full of hydrogen is a rather dangerous companion on a journey. Any spark is likely to set some leaking hydrogen on fire. (A spark and leaking hydrogen got together in the case of the huge *Hindenburg*.) Fortunately there is another gas, *helium*, that does not burn and therefore can be used with greater safety. Helium is now used in some of the large balloons. This gas is denser than hydrogen (1000 cu. ft. weigh about 11.2 lb.) and more expensive, yet the advantage of safety is often greater than the disadvantages of added density and cost.

A balloon floating in air is different in one very important way from a boat floating in water. It does not go all the way to the top of the air. Why is this true? To understand the answer to this question, you must remember that the air near the earth weighs more per cubic foot than the air high above the earth (page 319). That is, the weight of the air per cubic foot gets less and less as we go higher and higher. The upward push of the air on a balloon depends on the weight of the air it displaces.

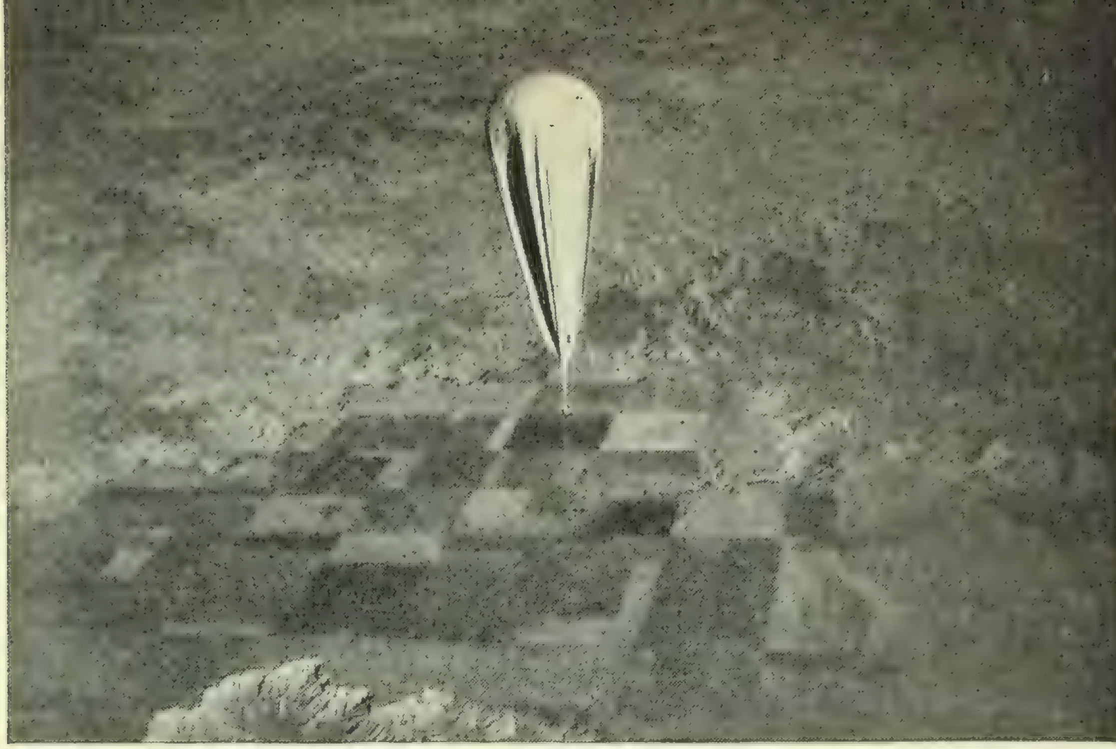

FIG. 508. The scientists in this balloon made a record flight into the *stratosphere* in 1935. When they reached the height of 72,395 feet above sea level, it was 43,254 feet higher than Mt. Everest, the highest mountain.

As it goes up, a balloon may displace 1000 cubic feet of air all the time. However, at the height of a mile, 1000 cubic feet of air weigh much less than the same amount of air weighs at the surface of the earth. When a rising balloon gets to the height where the weight of the air it displaces is equal to the weight of the balloon (including passengers, equipment and the gas in the balloon), it stops rising.

HOW ARE BALLOONS AND DIRIGIBLES CONTROLLED? Let us now see what the balloonist does when he goes on a trip in a balloon like those in Figure 508. First he must inflate the bag. As the gas rushes in, the bag grows larger and larger. At first the balloon displaces but little air; as it swells, it displaces more air. As a rule the bag is not fully inflated, because as it rises, the air-pressure gets less, and the gas in the balloon expands. As the gas inside the balloon expands, the automatic valve in the neck of the balloon opens when the pressure inside gets too great, and part of the gas escapes. The balloon continues to rise until it reaches a level where the air displaced equals the weight of the balloon. If the pilot wishes to go higher, he throws out *ballast*. This usually consists of bags of sand. Relieved of this weight, the balloon rises. If the pilot wishes to descend, he opens the valve and lets out part of the gas.

All of this time the balloonist is at the mercy of the wind. He does not feel the slightest air movement, because his balloon is

floating along at the same rate of speed as the wind. He has little means of telling how fast he is going or in what direction. As the balloon travels, it generally revolves slowly; therefore the compass does not tell the pilot his direction. If it were not for the leakage of gas, a balloon could remain in the air indefinitely. But because of this leakage it must finally come down. When it nears the ground, the heavy *trail rope* is of great assistance in making a good landing. When the balloon comes so low that the rope touches the ground, the balloon is relieved of part of its weight and becomes more buoyant. The dragging trail rope also cuts down the speed of the balloon.

The dirigible differs from the ordinary balloon in that the direction of its flight can be controlled. It is equipped with powerful motors operating propellers which force it through the air. By using huge rudders at the stern of the balloon it is possible to drive the dirigible upward, downward, or in a horizontal direction as well as to turn it from side to side.

*Self-Testing Exercises.* 1. (*a*) Is the pressure of the atmosphere greater against the bottom or the top of a balloon? (*b*) What causes the difference? (*c*) Why is this difference important?

2. Why are toy balloons filled with hydrogen?

3. Explain why the dirigible balloon, the *Hindenburg*, in addition to its own weight, was able to lift a load of about twenty-one tons against the force of gravity.

4. If soap bubbles are blown with the gas burned in stoves (illuminating gas), these bubbles will float up toward the ceiling. What does this tell you about the density of illuminating gas as compared with the density of air?

5. What determines how far up a balloon will go? How does the balloonist control the rising and sinking of the balloon?

*Problems to Solve.* 1. A balloon holds 12,000 cubic feet of hydrogen gas. The balloon with all its equipment weighs 900 pounds. How many pounds of crew, passengers, and ballast can it support?

2. Why can the toy balloons used on the Fourth of July rise into the air?

3. Every year international balloon races are held. Find out the distance record for balloons. Also find out the greatest altitude to which balloons have risen.

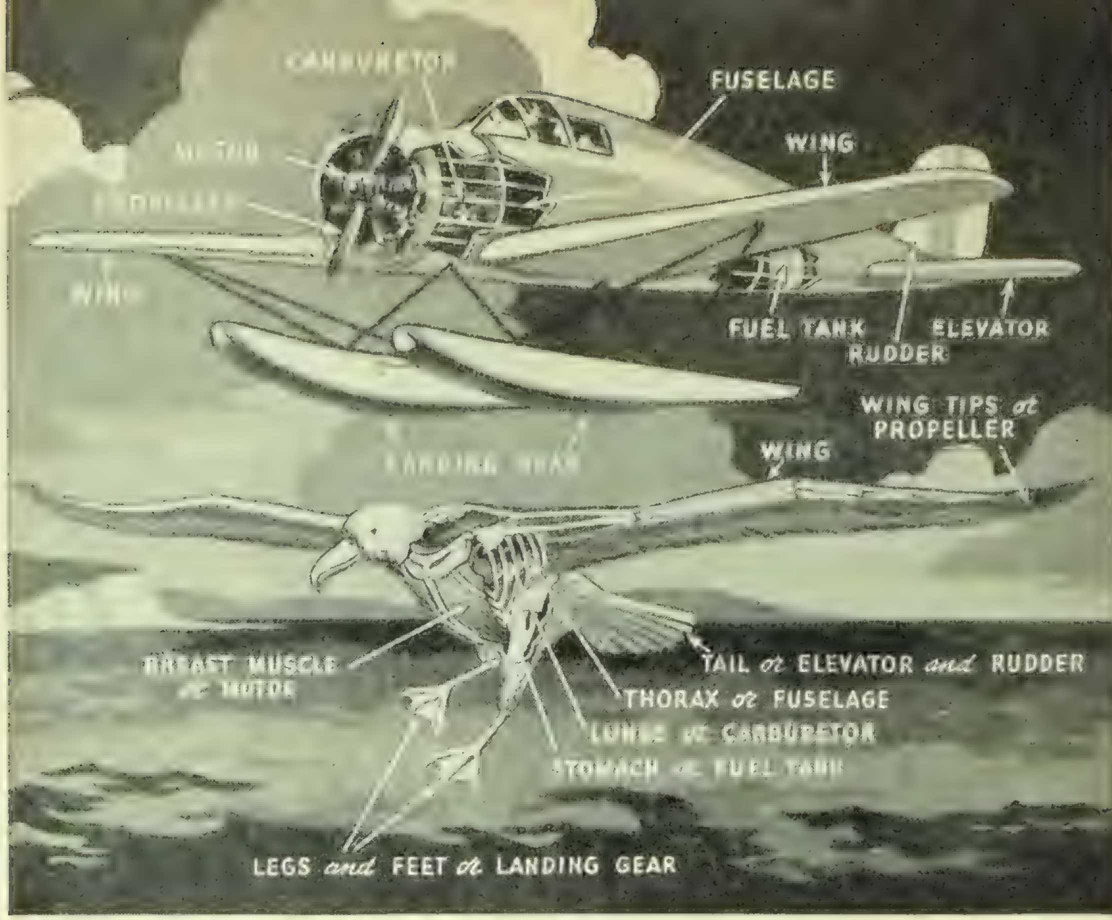


FIG. 509. This drawing shows you a comparison of a gull and a hydroplane. Study it carefully so that you can explain it fully. How does each get its energy?

## ¶4. How are aeroplanes held up?

HOW IS AN AEROPLANE CONSTRUCTED? The aeroplane has been closely modelled after the form and structure of the bird. The weight of its body is centred near the front, which counterbalances any tendency to whirl over backward. Its wings are arched, with concave side downward, and are thicker in the front than in the back. The body tapers toward the ends. This cuts down air resistance exactly as the body and head of a bird do. Its tail balances the effect of the wind on the plane so as to keep an even keel, and it furnishes the means of steering.

Aeroplanes are always driven with powerful engines, because to remain in the air it is necessary to keep a speed of fifty miles an hour or more. The propeller cuts through the air at the rate of 1500 or more revolutions a minute. Its action is like that of a screw. If you start a screw into a block of wood and turn it with a screw driver, its curved edges will cut through the wood, pulling the screw deeper and deeper into the wood. The blades of the propeller are curved in somewhat the same manner, and as they revolve they cut deeper and deeper into the air, pulling the aeroplane with them. Although the air is not solid like wood, its

resistance or inertia is great enough so that the propeller works its way through it like a screw with every revolution.

How does an aeroplane fly? If you have stood near the tracks when a rapidly moving train goes past, you have seen that as the rear of the train passes, there is a tremendous wind in the direction of the train. This wind is caused by a partial vacuum formed by the train. The train forces its way through the air at high speed, and the air behind the train is forced into the partial vacuum created as the train moves onward. A similar condition is created above and below the wings as the aeroplane rushes forward.

FIG. 510

Since an aeroplane weighs much more than the air that it displaces, it is necessary to have some upward force to counteract the downward pull of gravity. This upward force is secured through the proper wing construction. Figure 510 shows a side view of the wings, or planes. You can see that the wing surface is convex, that is, rounded upward. As the propellers draw the aeroplane through the air, a terrific wind strikes the plane. When an aeroplane is flying through the air at 200 miles an hour, the force of the wind against it is the same as if it were stationary and a 200-mile gale were blowing. The "hump" on the front edge of the plane throws the currents of air upward above the plane, as shown in Figure 510. This creates a partial vacuum above the plane. The air-pressure beneath the wing is therefore greater than the air-pressure above the wing.

It is this difference between the pressure on top of the wing and that on the bottom which produces most of the lifting force. The greater the speed of the plane, the greater the difference of pressure. You can now see why the aeroplane must be kept in motion. If the aeroplane were not moving, there would be no difference of pressure developed above and below the wings; therefore there would be no lifting force.

The upward and downward course of the aeroplane is governed by the elevator. The wings themselves are not placed at a great enough angle for the machine to "take off" when it is on the ground. When the aviator wishes to ascend, the engine is started, and the propeller pulls the machine along the ground. When the pilot is sure that the plane has gained sufficient speed, he pulls the proper lever, which lowers the elevator. The elevator is a small, movable piece, or rudder, located on the tail. When it is lowered (Figure 511), the pressure of the wind pushes the tail of the plane off the ground. If the elevator is now raised, the pressure of the wind pushes the tail down and the nose up. This allows the wind to strike the underside of the wings. The force of the wind lifts the aeroplane as it does a kite.

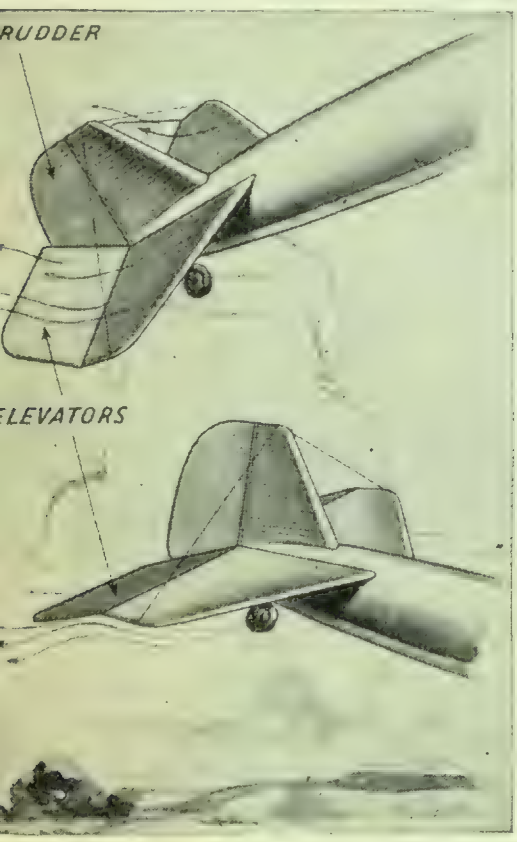

FIG. 511

In descending, the elevator is lowered, and the wind pressure lifts the tail and lowers the nose, thus decreasing the angle at which the wind strikes the wings. Moving up and down or flying at a level is thus accomplished by the raising or lowering of the elevator. The aeroplane is steered largely by means of the vertical rudder or rudders. These offer resistance to the air current, just as the elevators do. By moving them to the right or left, the pilot can change the direction of the plane.

*Self-Testing Exercise.* Outline the things an aviator must do to "take off," ascend to an altitude of 1000 feet, fly at this level for a mile, and then return to his starting place. Include in your outline an explanation of why the aviator must do the things he does and of how the force necessary to lift the plane is obtained.

## Looking Back at Unit 19

1. State in sentence form each of the principles, or big ideas, of science that you have learned from your study of this unit.

2. Study Figure 512 carefully and read what is said beneath the

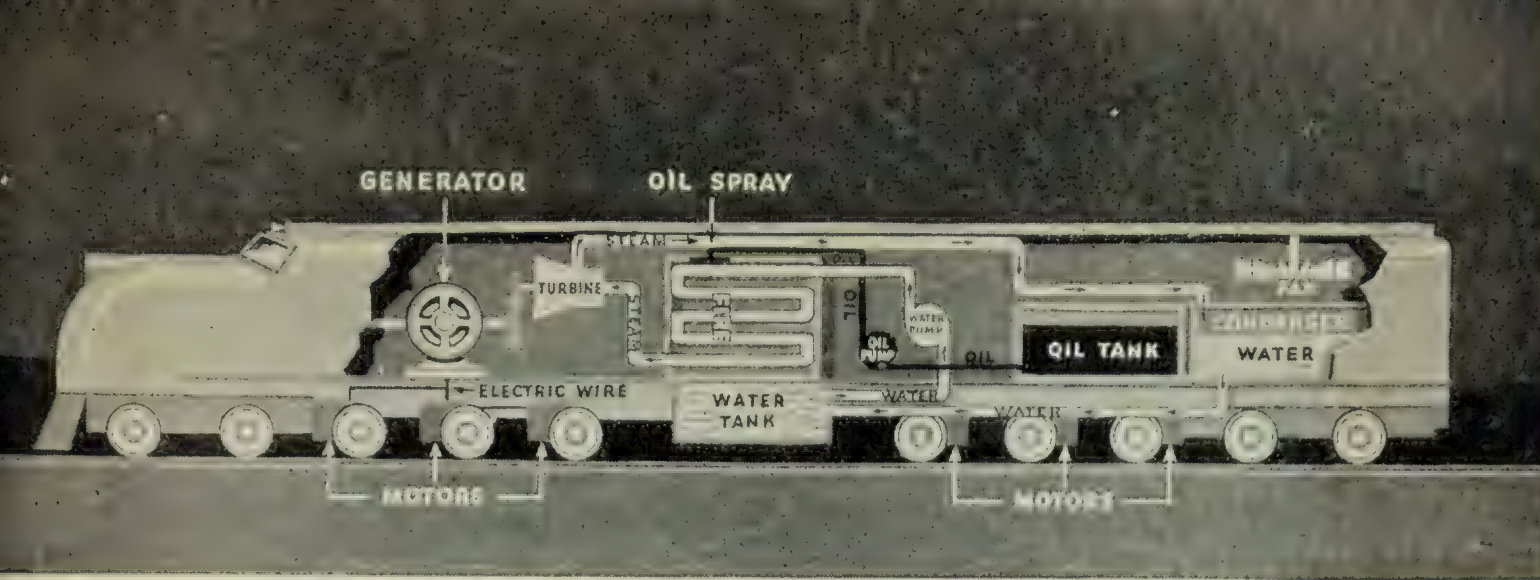


FIG. 512. The most modern stream-lined locomotives are run by electricity supplied by a generator. Power for the generator is supplied either by Diesel engines or by steam turbines, as above.

picture. Write an explanation of all that the picture shows. Especially explain every step in the harnessing and the transformation of the energy that runs the locomotive.

3. Explain or define each of these science terms:

| | | |
|---|---|---|
| *clutch* | *transmission* | *differential* |
| *fluid* | *Archimedes' Principle* | *chronometer* |
| *sextant* | *magnetic declination* | *compass card* |
| *knot* | *latitude* | *longitude* |

## Additional Exercises

1. State the advantages and disadvantages of transportation by land, by water, and by air.

2. Why is it easier to float in water if you take a deep breath?

3. Is it easier to swim in fresh water or salt water? Explain.

4. A flat-bottomed barge is twenty-five feet wide and one hundred feet long. How many thousand pounds of stone must be loaded to make it sink one foot more?

5. Why is it dangerous to drive fast on a wet pavement?

6. If you have ridden in an aeroplane, tell about your trip.

7. Why is it easier to steer an automobile on a muddy road when one is climbing a hill than when one is going down a hill?

8. How can an aviator determine the height at which he is flying?

9. Explain the effect of centrifugal force on an automobile when it turns a corner very rapidly.

10. Why are roads usually banked on the outside turn?

11. Find out what the traffic regulations are in your community.

12. Find out how railway signals operate.

13. Aviation experts believe it highly desirable to solve the problem of flying in the *stratosphere*. What is the stratosphere, what advantages are there in having planes fly there, and what problems does stratosphere flying involve?

FIG. 513. The *helicopter* can go straight up or down and even stand still in the air. It can also fly forward, backward, or sideways. The two large propellers on top, revolving in opposite directions, support and move the plane. The small propeller on the tail helps in steering. (DuPont photo)

## Books to Read

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WHEN DUCKS AT THE MIGRATORY WATERFOWL REFUGE get sick, they receive excellent care at the "duck hospital." This duck is being treated for "western duck sickness," a disease that has killed great numbers of ducks. And the doctors at this hospital do not mind being called "quack" doctors either. Steps are being taken by local communities, and the Governments of Canada and the United States to preserve native wild life. In this unit you will learn about the various aspects of the conservation problem and what you can do to help solve it. (Photo courtesy *Popular Science Monthly*)

# UNIT 20

# How Can Science Help Us Keep from Wasting Nature's Wealth?

## Looking Ahead to Unit 20

WHEN YOU TAKE A TRIP through different parts of the country, you enjoy seeing well-kept farms with their luxuriant crops. On your vacation you love to visit clear lakes and sparkling streams where there are fish to be caught. You want to hike through woods where wild animals can be seen. Of course, there are many places like the ones you have just read about.

However, on any long trip you are sure to find places that are entirely different. In many localities the soil is worn out, and the crops are poor. Gullies are slowly eating into the hillsides and making the land a desolate waste. In other places there are no trees, and even the covering of grass or other vegetation is gone. Perhaps dust-storms sweep across the land in dry weather, and floods may come suddenly when the rains are heavy. Unfortunately, places like the ones you have just read about are becoming all too common throughout our country.

For thousands of years before white men came to America, the soil of our country was slowly building up. Plant roots kept it from washing away, and decaying animals, leaves, and plant bodies added their material to make it rich. Of course, Indians raised crops before the white men came, but there were only about 500,000 Indians in the greater portion of the continent. When white men settled the Atlantic coast, they began to cut down trees for building materials and to clear fields for crops. The vast forests before them seemed inexhaustible. There was plenty of land; so new fields were cleared when the old ones began to produce poorer crops. Fire was often used to clear forest growth. This destroyed trees and other vegetation over large areas and ruined much organic matter that had protected

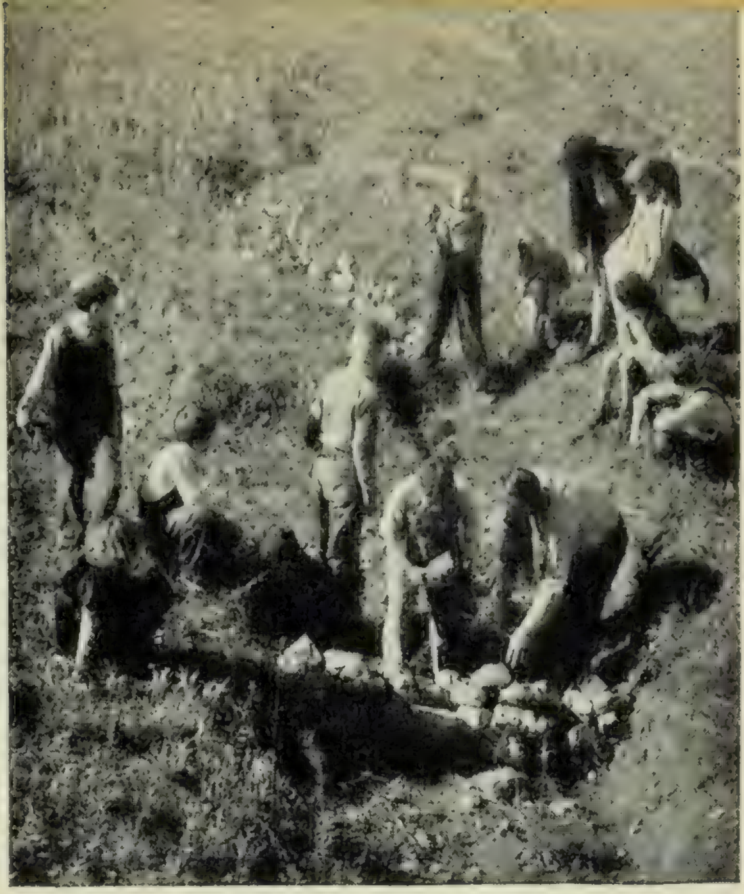

FIG. 514. By building *check dams* these children are helping prevent soil losses by erosion. The dams slow down the movement of water and give it more time to soak into the soil, and they also keep gullies from spreading. Check dams may be built of any available materials—rocks, brush, logs, or sod. (Photo by H. Mieth and O. Hagel from *Life*)

the surface of the land. Animals were slaughtered in large quantities, for the supply seemed greater than could ever be used.

As settlers began to spread westward over the country, the senseless destruction of natural resources spread with them. But the supply still seemed inexhaustible. And so civilization spread to all parts of the land, carrying with it the waste of soil, forests, animal life, and other natural resources.

All of this unwise use of resources has brought us face to face with serious problems. Our forests are almost gone; our land is being washed away; our supplies of coal and oil are being used up; our wild animals are disappearing; and floods and dust-storms have become a national problem. The worst feature of the whole problem is that once the destruction is started, it gets steadily worse and worse. Wild animals have disappeared from many places because their homes and breeding places have been destroyed and because people have been unwise in their hunting. Many streams have been "fished out" because fishermen were not satisfied with catching a reasonable number and putting back the fish that were too small for use. What are we going to do about this waste of our natural wealth?

About forty years ago a few scientists began to be alarmed at what was happening. They tried to get people to understand the importance of the problem and to plan far enough ahead to avoid exhausting the natural resources of our country. Most people paid little attention to them. In recent years, however, the pro-

tection and wise use of our natural resources has become so important that the federal and provincial governments spend millions of dollars each year on *conservation*. In addition, they are trying to make people everywhere understand the need of conservation. Your part in this important work is (1) to learn what some of the important problems of conservation are, (2) to learn some of the ways of solving these problems, and (3) to help by putting what you have learned into practice in your community.

## ¶ 1. How can we save our soil?

EVERY RAIN-STORM AND EVERY DUST-STORM in our country carries some of our valuable soil away. With each rain Alberta, Saskatchewan, and Manitoba are sending some of their soil to the Arctic Ocean. Parts of Ontario and Quebec are giving soil to the Great Lakes and the Gulf of St. Lawrence. The Maritime provinces are losing soil to the Atlantic Ocean, and British Columbia is losing it to the Pacific Ocean.

In most places in our country the average depth of the soil is from three to six feet. Of this, only about eighteen inches, or the upper layer, known as *top-soil*, is suitable for growing plants. If a truck load (one or two cubic yards) of soil is taken from an acre of land each week, you can scarcely notice it. But if this goes on for thirty years, about a foot of soil will be removed from the entire surface of the land. In some places we are losing soil this fast and even faster. Fortunately, however, erosion is occurring more slowly in most places. This loss of soil is a very serious matter to every one of us, because we depend upon the soil either directly or indirectly for food. In order to study the problem intelligently, you will need to know, first of all, something about the conditions that cause soil erosion.

WHAT ARE THE CONDITIONS THAT CAUSE SOIL EROSION? Over fifty-nine tons of rich soil per acre may be lost in one year from an acre of farm land that is planted in corn! This is almost unbelievable, yet government tests show that it is true. A test showed that only eight tons were lost in one year from an acre of similar land on which the crops were rotated. What causes this difference in the amounts of erosion? It is not merely that differ-

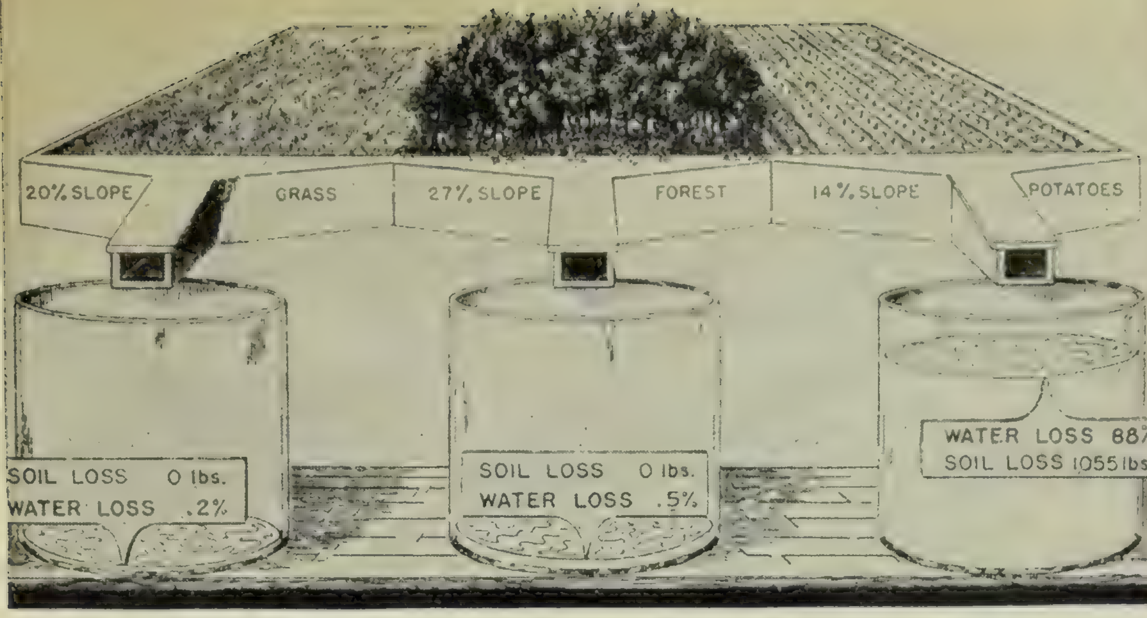


FIG. 515. This chart shows the results of studies carried on by the Soil Conservation Service Station near Ithaca, New York, from March 1 through March 19, 1936. The studies compare the soil and water losses from land of varying slope and under different vegetation. (Soil Conservation Service photo)

ent kinds of crops are planted, for there is no single cause of soil erosion in any one place. At least four different things affect erosion: (1) the amount of rain that falls and when it falls, (2) the slope of the land, (3) the kind of soil, and (4) the kind of farming that is carried on.

It is easy to understand that the amount of rainfall affects erosion. Some regions of Canada have an average of fifty inches of rainfall a year, while others have an average of only twenty inches a year. Of course, we would expect more erosion in regions of 50-inch rainfall. But a large amount of rainfall well distributed throughout the year will not cause nearly so much erosion as heavy rainfall in short periods. For example, the rain gauges at the Soil Conservation Experiment Station at Arnot, N. Y., showed that on June 19, 1936, an inch of rain fell in ten minutes. This one rainfall washed 7586 pounds of soil from one experimental plot of land. In the next six weeks only 1.7 inches of rain fell on the same area. During that time there was little erosion. Thus most erosion occurs during seasons of heavy rain.

Another important factor in erosion of soil is the slope of the land. You know that water always moves to the lowest possible level because of the pull of gravity. If the slope is steep, the water runs faster than if the slope is gentle. You know also that the faster water is moving, the more soil it can carry with it. Even on long, gentle slopes water gains speed as it runs downhill. Also,

FIG. 516. If the farmer plants corn, cotton, or other crops that leave the land bare between the rows, or if he plows his land in the fall and exposes it to the winter rains, erosion may occur very rapidly. (Soil Conservation Service photo)

the volume of water is greater toward the bottom of the slope. Thus, even on land that is sloping gently, rich, loose top-soil may be carried down to lower levels and finally to streams.

The problem the farmer faces is to get the rain water to soak into the ground or to run to the lower places without taking his soil along. And the steeper the slope, the greater his problem. To solve the problem, the farmer must study the *contour* (shape of the surface) of the land. From the contour of the land he can plan which way to run the rows, where to put strips of grass or other cover crops, or where to put his drainage tile or ditches.

A third important factor in erosion is the kind of soil. Coarse soils, such as sand and sandy *loam* (earth in which decaying leaves, etc., are mixed with clay and sand), absorb water more easily than most other kinds of soil. Therefore, these soils are not likely to suffer from erosion so much as the finer soils, because water sinks quickly into them instead of running off and carrying the soil with it. However, if a coarse soil is nearly all sand with no finer particles to help hold it together, much erosion will occur during heavy rains. Humus and other organic matter added to soil act as a sponge and help hold moisture.

Clay and clay loams do not absorb water quickly. They are made of such tiny particles that they pack together tightly and form a hard surface. Rain falling upon such soils runs off easily and carries much soil with it before it can sink into the ground. Perhaps you have seen streams that run over clay soils. You

know how muddy they are after a heavy rain. Once the tiny particles are in suspension in the water, even water that is moving slowly can carry them great distances.

The fourth factor that affects erosion is the way the farmer manages his crops. If he keeps his land planted in grass or other crops that have masses of fine roots, erosion will be kept down to a considerable extent. Government tests show that an acre of one kind of land planted in bluegrass lost only 100 pounds of soil during a year. Similar land on which other kinds of crops were planted (corn and cotton, for example) lost much greater amounts of soil per year. Leaving some of the land in woods helps greatly. Tree roots help hold the soil, and the covering of fallen leaves helps hold moisture and prevent erosion. The use of crop rotation or a combination of crops, such as cowpeas planted in corn, helps reduce erosion. The federal Department of Agriculture has carried on experiments to discover which crops best prevent erosion. Grass, alfalfa, clover, trees, and shrubs will do the most toward checking erosion. The next best are oats, wheat, rye, and barley. The poorest are row crops, such as corn, cotton, potatoes, tobacco, and truck crops.

*Self-Testing Exercises.* 1. Why does the amount of rainfall play an important part in erosion?

2. Why does the distribution of rainfall according to months affect the amount of erosion? Give an illustration.

3. Explain what is meant by the contour of land? How does the contour affect erosion?

4. What kinds of soils erode most easily? Least easily? Why?

5. With what kinds of crops grown in your locality do you think the soil washes away the least? With which do you think it washes away the most?

*Problems to Solve.* 1. Examine places in your community where erosion is taking place and where it is not occurring. Do your findings agree with your answer for Self-Testing Exercise 5? Why?

2. (*a*) Is erosion a serious problem in your community? (*b*) If so, are landowners aware of the problem?

3. Ask your teacher to write the Bureau of Geology and Topography in Ottawa for a contour map of your locality. Study the contour of the land where you live. Visit different places where erosion is taking place. Mark these places on the map.

FIG. 517. Contour farming, in addition to controlling soil erosion, makes field work easier on the farmer, the teams, and the machinery, since they are travelling nearly on a level instead of up and down slope. (International Harvester Company photo)

WHAT ARE SOME OF THE WAYS OF CONTROLLING SOIL EROSION? Did you ever hear anyone use the expression, "trying to fit a square peg into a round hole"? He was probably speaking of trying to make something work that would not work as he wanted it to. That is exactly what has been done in farming in the past. We have tried to lay off all our fields in squares or rectangles, that would not fit around hillsides or sloping river bottoms. The result was hard work for the farmer in cultivating fields and the loss of much soil. When rows run up and down hillsides, heavy erosion takes place with each rain. The rows form channels in which the water can run faster down the hillsides.

In recent years there has come into use a way of laying out fields so that the rows go across the slopes of hills instead of up and down. This way of plowing is known as *contour farming* (Figure 517). When you think of it, this seems the most natural way to plan fields. Rows that go across slopes form many little dams that hold the water when it rains. In this way much of the water can sink into the ground instead of rushing down and washing away soil as it goes. Furthermore, seeds are not so easily washed away in contour farming as in the older straight rows. Many a farmer has planted seeds in rows that ran up and down a hill, only to have them washed away before they could germinate and get their roots firmly anchored in the soil.

Another method of preventing soil erosion is *strip cropping*. This way of planting includes contour farming, as you will see.

Instead of planting crops in large fields, the crops are planted in strips of uniform width. Like the rows in contour farming, these strips run across the slope and not up and down (Figure 518). Strip cropping has a special advantage. Strips of crops like corn, tobacco, or potatoes have strips of grass, wheat, or soy-beans in between them. Soil that is washed down from the cleanly cultivated crops is stopped by the thick growth in the strip below. Experiments show that the width of the strips may vary from fifty to about 125 feet. In general, narrower strips should be planned for steeper slopes. If the strips are very wide, gaps may wash out in individual strips just as they would on a bare hillside.

Strip cropping has two other advantages. Crops are easier to cultivate and harvest, and they may be rotated more easily. For example, the strip that was planted in corn the first year may be planted in grass or wheat the next year; while the strip that was planted in grass or other small grain the first year may be planted in corn the second year, and so on. In this way many different kinds of rotation may be planned to keep the soil fertile while the stripping is helping to prevent erosion.

Still another method of preventing soil erosion is *terracing* (Figure 519). When this plan is used, the long, steep slopes of hillsides are built into short, gradual slopes something like steps. The rows of crops on the terraces go around the hillside. In most terracing, shallow drainage ditches that follow the contour of the land must be provided on each terrace. These ditches lead the water into a general drainage outlet in the field.

FIG. 518. An aerial view of a farm, planned to conserve soil, shows how the fields have been laid out carefully for alternate strips of alfalfa and corn. (Soil Conservation Service photo)

FIG. 519. This fertile wheat-field has well-built terraces to protect it from excessive water run-off and erosion. (Soil Conservation Service photo)

Careful farmers use many other simple devices to prevent erosion. They plant winter cover crops, such as rye, wheat, and other similar crops, to keep down much erosion during the season when rains are plentiful. They leave steep slopes for pasture or for wood lots. Permanent pasture crops are an ideal solution to the erosion problem in places where the steep slope of the land makes the raising of other kinds of crops unprofitable because of erosion. In many permanent pastures soil experts have found it wise to plow deep furrows at intervals around the steep hillsides. Such furrows hold water and let it sink into the soil. Tests show that pasture furrows let water go from six to eighteen inches deeper in soil than it will go in pastures with no furrows.

Another way of helping prevent erosion is planting grass in drainage ditches. Grassy coverings in ditches and other waterways hold back the water until it flows so slowly that little erosion occurs. Also, the roots hold the soil in place. Trees, shrubs, and vines along fence rows, in the bottoms of gullies, and at the heads of gullies help check or prevent erosion.

In all this discussion of controlling soil erosion, there are two things to keep in mind: (1) No single method is of much value by itself, and (2) the methods to be used must be determined by the kind of land and its particular features.

*Self-Testing Exercises.* 1. Close your book and write a brief paragraph telling what each of the following methods of cultivation is and how it helps prevent soil erosion: contour farming, strip cropping, and terracing. Then check with the book to see if you have omitted any important points.

2. Why does each of the following prevent loss of soil: *winter cover crops, permanent pasturage, planting grass in drainage ditches, planting or leaving wood lots?* Think of some of the disadvantages of using these methods.

*Problems to Solve.* 1. Write to your provincial experiment station or to the federal Department of Agriculture for bulletins on the control of erosion. Read them to learn details that could not be given in this book.

2. With the help of your classmates, work out a conservation project to use in stopping soil erosion on your school ground or in some other place where it is a problem.

3. Is maintaining soil fertility true conservation? Write a composition in which you discuss this problem.

## 2. How can we save fuel for future use?

In one year over 500,000,000 tons of coal were mined in Canada and the United States. In the same year 1105.5 million barrels of crude petroleum and 1,950,036 million cubic feet of natural gas were taken from the ground. These figures seem so staggering that we can scarcely believe them, but the statistics in a government report show that they are true.

When we use coal, petroleum, and natural gas, we are drawing upon the energy savings of the past, and these energy savings cannot be replaced when they are gone. Just how long our present supplies will last no one knows. Scientists believe that the present supply of coal will probably last from 1000 to 4000 years and that the supply of oil will last for a much shorter time. Coal and petroleum provide about 95 per cent of the energy used in our country. Since we depend so largely upon these materials for our energy supply, and since we cannot replace these materials when they are gone, we face another very serious conservation problem.

One thing is certain: We will continue to use our natural fuels as long as they last. Our chief problem, then, is to learn how to use them so that we can get the most good from them with the least amount of waste. Here the coöperation of science and industry is most important. Science must find the most efficient ways of using fuels, and industry must put into practice the various methods that are learned.

How can the supply of coal be conserved? For many years we have each year wasted enough coal on this continent to supply all of the homes in our country for another year. This amount of wasted coal would keep all of our railroads in operation for about eight months out of the year. One of the greatest sources of waste was in mining. One scientist estimated that only about fifty per cent of the coal in mines was ever taken from the ground. This left almost half of our coal supply in the earth, where it will never be mined. Safer and more thorough methods of mining have been introduced to make more of our entire coal supply available.

Another way of conserving our coal supply is by using it economically. Let us see how our coal supply is now being used. Industrial plants use the greatest amount, railroads the next greatest amount, coke manufacturers next, homes next, public power-plants next, and the manufacturers of gas least. We also sell some coal to other countries, but not much. Chemists tell us that about thirty-five per cent of the energy from burning coal goes up the chimney. This amounts to several million dollars each year.

One of the ways of saving much of this waste is by making coke from the coal and using the coke for fuel. As the coke is made, such by-products as gas, coal-tar, ammonia, and others are given off. These can be saved and used in various ways. For example, coal-tar can be made into liquid ammonia, creosote, and various kinds of oils. Other products, such as dyestuffs, perfumes, and paints, can be obtained from these substances. Coke is an excellent fuel. It burns with very little smoke, and since it contains as much as 85 per cent carbon, it gives off a great amount of heat when it is burned. Coke is used in blast furnaces for extracting iron from iron ore and for other heating purposes where great amounts of heat are needed. So one way of conserving coal is to make it into coke.

Another way of saving coal is by regulating the amount of air that gets into the fire. The hottest fires need just the correct amount of oxygen for each pound of coal that is burned. Too much air causes too rapid burning, which lets much of the heat escape up the chimney. Too little air and other wrong conditions

cause smoke. When black smoke is formed, unburned carbon (soot) is going up the chimney. Special ways of feeding coal into furnaces and special ways of admitting air eliminate much of this waste. Since the greatest amounts of coal are used by industries, it is in manufacturing plants that most coal could be saved. However, this does not mean that anyone, in the smallest home or in the largest industrial plant, is justified in using coal in wasteful ways. The laws require that every boiler must have a steam gauge and a safety valve to prevent explosions. Why not have and enforce laws requiring people to use devices for saving fuel?

Still another way of saving coal is by having very large power-plants use coal to produce electricity and then distribute the electrical power to the small plants that need it. Tests have shown that large power-plants are six or seven times as economical as small plants. This is just one illustration of how science can help save fuels. You learned on page 504 that steam turbines are much more efficient than ordinary steam engines. They use about 28 per cent of the energy of fuels, where other engines may use 10 per cent or less. Wherever possible, the more efficient turbines should be used.

Fuel may also be saved by substituting water power for steam power. On page 493 you learned that only a small amount of the available water power in Canada is being used. In spite of the disadvantages of using water power (page 493), more of it can be used as better methods of transmitting electricity are developed. Artificial fuels, too, will help save coal. And even wood still has a place as fuel. In sawmills and wood-working plants waste wood can often be used as an economical source of power.

*Self-Testing Exercises.* 1. Make a list of the ways of saving coal suggested in this problem. Try to think of some of the advantages and disadvantages of putting each of these methods into operation.

2. Explain why making coal into coke and using it for fuel helps conserve our fuel supply.

3. What other sources of energy can we hope to use in the place of coal? (See Unit 15.)

*Problems to Solve.* 1. In some good reference book find what by-products (including those mentioned in this book) are made from coal. Try to find out how some of these by-products are made.

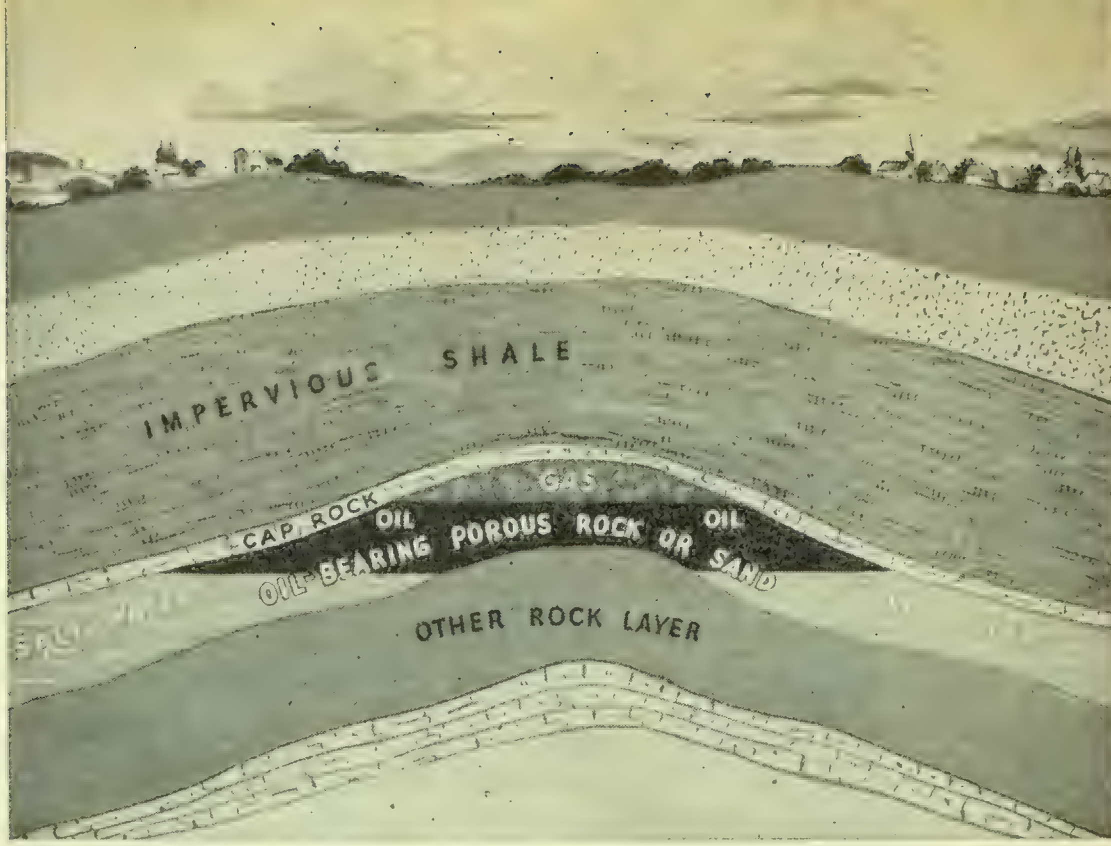


FIG. 520. Oil-bearing layers of rock

2. What methods of coal conservation are in use in your community? Suggest how other methods could be used.

3. Make a map of Canada showing the location of the principal coal fields.

4. In a reference book read how coal is mined. List any suggestions for improvements in mining methods.

HOW CAN OUR SUPPLY OF OIL BE MADE TO LAST LONGER? In Canada and the United States almost 17 billion gallons of gasoline are used by automobiles in one year. As you have learned, scientists do not know how long our present supply of oil will last because they do not know how many more oil deposits may be discovered. Several hundreds years, at least, is a good estimate. When we think of the vast amount of petroleum that is used each year, we wonder what man will do when this valuable natural resource is gone.

Not only is petroleum used for making gasoline. Much of it is used as *fuel oil* for operating Diesel engines and for heating buildings. In addition, many valuable by-products are made from petroleum. Lubricating oils of various kinds for machinery, petroleum jelly (vaseline) for salves and medicine, paraffin for waterproofing, canning, and other household purposes, gasoline, naphtha, kerosene, and even one kind of chewing-gum are but a few examples. Since petroleum is so important to us, do you wonder that scientists are trying to find ways of conserving it?

Most people have strange notions about how we get oil from the ground. The popular belief is that pipes are driven down into huge underground lakes of oil and that the pressure of the earth makes the oil gush out. What are the facts? Hundreds or thousands of feet down in the earth are huge domes of rock layers (Figure 520). At the tops of these domes gas, which is lighter than oil, collects in porous sandstone. The gas cannot escape; so it exerts great pressure in all directions. Below the gas are other layers of porous rock or sand that hold the precious oil like a sponge. Beneath the oil-bearing layers is usually salt water, which is heavier than oil. Salt water also exerts pressure on the porous oil-bearing sand. Under natural conditions the pressure of the gas from above and of the salt water below "squeezes" oil from the oil-bearing sand or rock and makes it flow up through the pipes of the well.

The oil prospector comes along and uses sensitive instruments to help him estimate where the dome is. Then drills are used to bore down through the dome, and pipes are sunk as the drilling is done. The drill usually reaches the gas pocket first, and billions of cubic feet of valuable gas are allowed to escape so that the oil can be reached. Then the drill reaches the porous rock or oil-soaked sand, and the oil either spouts out under natural pressure or is pumped out. Finally, salt water begins to come up. People used to think that when this happens, the well is "through." But actually about seventy-five per cent of the oil still remains in the ground, never to be brought to the surface and used.

Here is where scientific conservation methods come into the picture. About 1903 a clever mining engineer got the idea that if the gas in the top of the underground pocket could be kept in, the pressure it exerted on the porous rock or oil sand (plus the pressure of the salt water from beneath) would continue to force oil out of the ground. He found a way to force gas into a well that seemingly had "gone dry." Much to his delight, he found that the well began to flow again. By this method, in most cases fifty per cent more oil can be taken from wells. What a saving this is! And what is more, when the oil is really exhausted, a great reservoir of natural gas still remains. This gas can be used whenever it is needed because the pipes keep it under control.

All of this sounds as if an important part of our oil-conservation problem is solved. But, unfortunately, such is not the case. For every well that uses this method of *re-pressuring*, there are ten that do not use it. Much needs to be done to convince operators that re-pressuring is an economical thing to do. Also, well-owners have to learn to coöperate with each other to make this method a success. When an oil well is found, everyone who owns or controls near-by land drills wells. This is done so that each owner will get as much oil as possible before the supply gives out.

Not only must we get all of the oil possible out of wells that are already being used, but we must use oil wisely after we get it. Science has found a way of saving oil in the production of gasoline. It is called *cracking*. The oil is heated under great pressure to temperatures higher than the boiling point of gasoline. These high temperatures break up the heavier oil molecules into lighter gasoline molecules. "Cracking" oil gives almost twice as much gasoline from a gallon of oil as plain distillation gives. This process makes our valuable oil go farther in providing gasoline.

Undoubtedly substitute fuels will come into use as the supply of oil becomes smaller and the price rises higher. Alcohol can be made from crops that grow each year and can be mixed with gasoline to drive automobiles. Much gasoline could also be saved by using smaller engines in our automobiles. However, so long as gasoline is not too expensive, substitute fuels and smaller motors will probably not be used. So we shall have to rely upon increasing our yields from oil wells and upon discovering new ones to add to our supplies for the present.

*Self-Testing Exercises.* 1. Tell in your own words why oil flows out of an oil well under natural conditions.

2. What petroleum products have you used or seen used? Try to add others to the list that is given on page 694.

3. Explain how an oil well may be re-pressured.

4. Close your book and make a list of the ways in which oil may be saved. Check with other sources and add other ways.

*Problems to Solve.* 1. How do drillers of oil wells keep the oil and gas under control? Look in reference books and science magazines.

2. Read in some good reference books to learn more about "cracking" oil. Prepare an oral report for your class on this topic.

## 3. How can we best enjoy our wild animals?

TWO HUNDRED AND FIFTY YEARS AGO, the wild life of Canada was its great treasure; a hundred and fifty years ago, the fur-trade was unrolling the whole western half of the map of Canada. Today we find that many of our wild animals are gone. The supply was far from unlimited. Our birds, small fur-bearing animals, large mammals, fish, and other wild creatures have disappeared at such an alarming rate that we must do something about it. Unless people everywhere recognize how serious the problem is, practically all of our wild life will become extinct. Perhaps you know that the dodo bird, the passenger pigeon, and the heath hen have disappeared because of man's destructiveness. Others will soon follow. Instead of giving thanks for the unlimited supply of wild life, the people of our country must now try to find ways of conserving the kinds of wild life that are left. How can we attack the problem in a scientific manner? What is your part in helping to solve it?

WHY ARE OUR WILD ANIMALS DISAPPEARING SO RAPIDLY? One of the first things to do in solving a problem is to find what is causing the trouble. Why is our wild life disappearing so rapidly? One reason is that we have destroyed their breeding and feeding places. For example, industrious farmers practise *clean farming;* that is, they cut all the bushes and weeds in fence corners, along ditch banks, and at the edges of woods. This has destroyed the places where quail, prairie-chickens, and other birds can nest, feed, and find shelter. Many scientists think clean farming is one of the most serious causes of destruction of bird life. Under older methods of farming, when rail fences were in use, things were different. There was space in fence corners and other places where plants could grow and protect the birds. Of course, we cannot go back to the old days of rail fences. That would be a waste of wood. But it is possible to restore the bird population in as little time as ten or fifteen years if we go about it properly.

The same thing is true of animals, such as deer, bear, raccoons, beavers, bison, and many others. For example, various species of deer are noted for their habit of seeking the shelter and protection of forests. Since forests have been destroyed to such

a great extent, the numbers of these animals have greatly decreased. The draining of swamps and ponds has robbed beavers of their natural habitats and has caused their complete disappearance in many places.

In addition to saving the natural habitats of birds and other wild life, there is something else we must do to help them. The natural enemies of animals, game birds in particular, have been increasing. Stray cats and harmful kinds of hawks are good examples. Remember, however, that not all kinds of hawks are harmful. Some people try to kill any kind of hawk they see. This is very unwise, because there are only three kinds of hawks that are believed to be definitely harmful to other birds. These are the sharp-shinned hawk, the Cooper's hawk, and the duck-hawk. The first two destroy small game and poultry, while the duck-hawk destroys large numbers of water-fowl. The American goshawk is another of the birds of prey that destroy game birds that cannot defend themselves against attack. Other kinds of hawks are either entirely helpful or do as much good as they do harm. The main thing to remember here, however, is that natural enemies of many of our game animals are increasing, while the opportunities for the game animals to increase are becoming less and less.

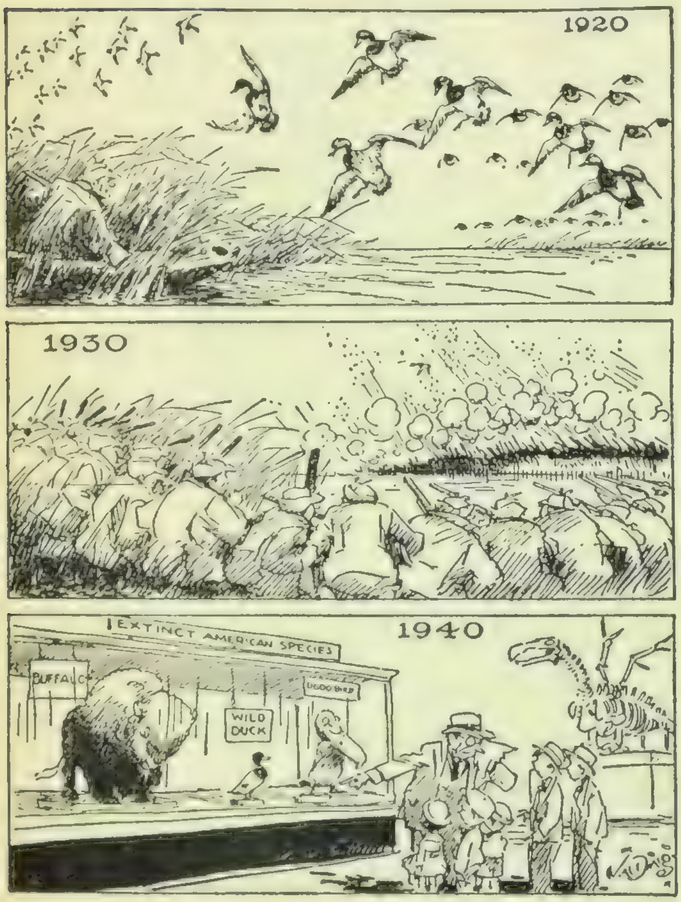


FIG. 521. Wasteful hunting may result in the disappearance of the wild duck. (Courtesy *New York Herald Tribune*)

Another very important reason why wild life is decreasing so rapidly in our country is the methods of hunting, fishing, and trapping that are practised in many places. Conservation of wild life does not mean that our people should not hunt, trap, and fish. It means that people who hunt, trap, and fish either for pleasure or to earn a living must use common sense in their methods.

Truly, man is the worst enemy of many of the things that are most valuable to him.

The invention of more effective guns, traps, and fishing equipment has added to the destruction of our game. Have you ever heard sportsmen boast about the number of fish they caught or the number of birds they killed? These people are often the ones who complain the most that all of our wild life is disappearing. They enjoy hunting and fishing, yet they are unwilling to do the things that need to be done in order that they may continue to enjoy their sport. All the sportsmen, as well as everyone else, must work together if we are to succeed in saving our wild animals.

*Self-Testing Exercises.* 1. Make a list of reasons why wild life is disappearing so rapidly in most places. Which of these reasons apply to your own locality? Add others that are not given in your book.

2. What are some of the natural enemies of wild life in your neighborhood?

HOW CAN WE FIND WHICH ANIMALS SHOULD BE SAVED? Some of the questions we should ask about an animal before we decide to protect it are: Is it of value to sportsmen? Is it of practical value to man for other purposes than hunting? Will it add to our pleasure when we see it on hikes and field trips? What effect will protection of this animal have on other animals?

Here is an example of a scientific way of discovering whether an animal is helpful or harmful to man. Experts from university departments of biology have examined the contents of the stomachs of hundreds of red-shouldered hawks. This bird was believed by many people to be harmful. What do you suppose the experts learned? About ninety per cent of the food of this hawk consists of animals that injure our crops or pastures, and only about one and one-half per cent of its food is farm poultry or game animals. Surely a bird that does this much good must be saved! Be sure to note, too, the scientific way in which the facts were learned. When we deliberately decide that certain wild animals must be destroyed, we cannot make our decision by hearsay or what someone merely thinks. We must have scientific evidence about their helpfulness or harmfulness and about their effect on other kinds of living things in the community.

This method has also been used to find what wild animals use for food. Many kinds of animals, for example, minks and weasels, occasionally steal poultry. But more often they pay for their damage by eating great numbers of field-mice and other small animals that destroy our food plants. Similarly, skunks feed upon mice, grubs, and harmful insects, while badgers feed on ground-squirrels, small burrowing animals, and insects. So now, when we want to find which animals are helpful and which are harmful, all we have to do in most cases is consult books written by people who have made investigations and have studied the facts with great care.

Before we decide whether a certain kind of animal should be protected, we would want to know also whether it has enough natural enemies to keep it in check, or whether it is likely to become a pest. It is very unwise to bring new animals into our country or to try to increase the numbers of certain kinds of animals unless expert biologists are consulted. These biologists study the problem carefully and make experiments to be sure that an animal will not increase to such an extent that it will become a pest. The mongoose of India was brought to Jamaica and other near-by islands to destroy rats, lizards, and snakes. Later it became a great pest. It ate chickens, birds, small farm animals, and sometimes fruit. The same thing can happen if we allow certain kinds of native animals to increase too rapidly. Therefore our national and provincial governments employ specialists to study the problem of conservation from all angles to find how increased numbers of animals will fit into the scheme of living things.

Some of the important game animals of our country are deer, bear, moose, foxes, wolves, wildcats, and even rabbits. A few of these, such as wolves and wildcats, are considered harmful and are not protected in most places. Many animals are of value as fur producers. These should be preserved at all times and hunted only according to carefully planned game laws. The important fur-bearing animals are minks, weasels, otters, skunks, muskrats, wolverines, badgers, raccoons, foxes, bears, and martens. The important game birds are quail, grouse, wild turkeys, pheasants, and ducks. Other kinds of birds are valued for their songs or for their beautiful plumage.

FIG. 522. A brown thrasher with a leg band. The picture shows how to hold a bird without frightening and injuring it. The fingers, held lightly around the neck, quiet it; the thumb (raised for the picture) rests on the wing to prevent fluttering, while the bird perches on the little finger. (U. S. Bureau of Biological Survey photo)

*Self-Testing Exercise.* Explain why the problem of conservation should be studied carefully in trying to find what animals need to be protected.

*Problems to Solve.* 1. Make a list of (*a*) wild animals that you consider helpful in your community and (*b*) those that you believe to be harmful. Give your reasons for placing them in either list. Read government bulletins or other references to see whether you agree with them about the animals you have listed.

2. With the help of your classmates find what animals are now protected by law in your community. Add to the list other animals that you think should be protected. In each case give definite reasons why you think these animals should be protected.

WHAT ARE SOME OF THE WAYS OF CONSERVING WILD ANIMALS? Have you ever heard of birds wearing "bracelets" like the one in Figure 522? For years interested people in Canada have operated bird-banding stations for the purpose of tracing the migration routes of birds. These birds are caught in harmless traps, and a band with a number on it is fastened around one leg. A record is kept of the kind of bird, when and where it was banded, and the number. When this bird is again captured, the number, location and date are reported.

In this way the migration routes and the dates of these journeys are learned, because bird-banding stations have been established

Fig. 523. At bird sanctuaries such as this in many places in Canada, mallards, black ducks, and many other ducks take advantage of the security and the daily rations of grain.

in many parts of the world. Then bird sanctuaries are established in many places along the routes, especially along waterways (Figure 523). In these sanctuaries no one is allowed to kill the birds, and food and shelter are provided. Thus many birds that might be killed make their seasonal migration journeys safely. You, too, can help save birds and other animals. You can build bird homes and feeding stations, and you can help keep animal enemies, such as stray cats, in check. Scouts, bird clubs, and other organizations are of great help in carrying out this valuable work.

In a similar manner game preserves are set aside by the national and provincial governments and by a few private organizations. Many of these places are operated in connection with provincial and national parks. Here trees and shrubs are planted for food and protection, and hunting and trapping are forbidden. In the United States, the state of Maine, where the people depend upon visiting hunters for some of their income, is using the most modern methods in caring for the animals in such preserves. In some parts of that state the game wardens patrol their areas in planes. When the snow is deep and stays on the ground for long periods of time, sometimes large herds of deer and moose are unable to find food. Wardens in planes locate these herds easily, land their planes on skis, and chop down evergreens for food and make trails to places where food can be found. If planes cannot land, food is dropped to the animals. Farmers can follow the government's example in leaving trees and shrubs on their land (or planting them), thus providing food, breeding places,

and shelter for large numbers of animals that would otherwise die. Often swampy places and streams are set aside as homes for beavers, muskrats, and other water animals. In these wild-life preserves no one is allowed to hunt or trap.

Did you ever hear of streams or lakes that are "fished out"? Fishing is great sport, and so many people enjoy it that our lakes and streams have become almost empty of fish. To re-stock such places and to stock places that do not have certain kinds of fish, national and provincial governments operate fish hatcheries all over our country. The men in charge of these hatcheries make surveys to find the best kinds of fish to put in different localities. They provide millions of fish from the hatcheries and help put them in places where they are needed.

In many parts of our country there are fur farms to provide furs for commercial use. Hunting and trapping have greatly cut down the number of fur-bearing animals. However, people still want furs. So, to meet the demand, fox farms, mink farms, and other animal farms have been established. They undoubtedly save many wild animals from destruction.

Other efforts to conserve animal life are the prevention of forest fires and the study of diseases of wild animals. Forest rangers with their fire towers and their forest patrols help in preventing forest fires. These fires not only kill or drive out wild life, but they destroy food and the natural homes of animals. National governments have spent much time and money studying animal diseases and ways of preventing them. In Canada the Science Service of the Department of Agriculture, the Institute of Parasitology at McGill University, and other organizations investigate diseases as they affect Canadian animals. The protection of birds has become an international concern. Did you know that Canada and the United States agreed by treaty to pass laws protecting migratory birds that spend the summer in Canada and the winter in the United States? Similar treaties have since been made in many countries.

The game laws are designed to protect our wild life. These laws are carefully planned to prevent the killing of animals during the breeding season and to limit the number that can be killed by any person during one day or during the hunting season.

FIG. 524. Raising pheasants is an interesting project for young people's clubs in rural areas.

By these laws we help conserve the supply of wild life so that there will be animals to hunt in the future. Hunting and fishing licences are required in most places, and the money from these is used to pay game wardens and for other conservation purposes. Special licences are issued to collectors of animal specimens for museums and other scientific institutions.

Probably one of the greatest needs of saving our wild animals is the development of good sportsmanship among people who love to hunt and fish. Hunters and fishermen should willingly buy their licences, because the money is used for the sportsman's own good. Hunters should never kill or trap more game than the law allows, even though they may feel sure that they will not be caught by the game warden. Fishermen should obey the law regarding the number of fish they are allowed to catch, and they should put back into the water any fish that are under the size prescribed by the law. Finally, people who are to enjoy our wild life should be willing to coöperate in every way possible in trying to save our animals. These are but a few examples of the sportsman's code. Can you add any others? Are you a good sportsman?

*Self-Testing Exercises.* 1. List as many different ways as you can of protecting wild life. Check with your book to see whether you have omitted any mentioned there. Give examples (from your own observations, if possible) to show how these ways work.

2. Which of the agencies mentioned in your book are operating to protect animals in your locality? Are there others not mentioned in the book? List them.

*Problems to Solve.* 1. Make a map of your province or of the Dominion. Show by means of color where National Parks, bird sanctuaries, and game preserves are located.

2. Get a copy of the game laws in your province and study them carefully so that you will understand better what is being done to protect animal life.

## ¶4. How can we make the best use of our forests?

OUR FORESTS PROVIDE LUMBER FOR HOUSES, cross-ties for railroad tracks, fence and telegraph poles, piling for bridges, and material for making barrels, boxes, crates, and furniture. In some parts of our country the forests furnish us with fuel. Resin, turpentine, and tannin are other valuable forest products. Even the paper on which this book is printed is made of wood pulp.

Notice in Table 20 what becomes of the wood in a typical tree that is cut for our use. Only a little over one-third of the material of the entire tree is available for use as lumber! Fortunately, however, not all of the other 63 per cent is wasted. The increas-

TABLE 20. WHAT BECOMES OF THE WOOD IN A TREE

| | |
|---|---|
| Left in stump, limbs, and top | 18.9 per cent |
| Bark | 10.5 " " |
| Sawdust | 11 " " |
| Slabs from sides of logs | 7.1 " " |
| Trimmings and edgings from boards | 7.1 " " |
| Careless waste | 2.8 " " |
| Weight lost in drying | 5 " " |
| Seasoned, undressed lumber | 37.6 " " |

ing scarcity of wood has made us learn to use practically all of the tree. For example, the limbs are used for fuel, trees are being cut closer to the ground, leaving little waste as stumps, and sawdust is even being made into paper pulp. Another way of saving some kinds of wood is called *veneering*. Instead of making furniture and other articles of solid oak, walnut, or other scarce wood, rapidly revolving knives cut the wood into large sheets almost as thin as paper. These sheets are glued over cheaper wood, and the result is a product that looks as well as solid oak or walnut. In this way valuable wood can be made to go farther than it otherwise would.

Fig. 525. Canadian forests are vanishing at a rate of thousands of millions of cubic feet every year. Here is one woodlot stripped by wasteful lumbering operations.

Fig. 526. To check this depletion, foresters are replacing the destroyed trees with young stands, like this new growth of Douglas Fir. (British Columbia Forest Branch photos)

The problem of forest conservation is not a new one. The first settlers in Canada burned great piles of timber to clear farms in the forest. Yet by 1840 people in Belleville were gathering driftwood for fuel. Since then the shortage has become greater each year as more and more of our forests have been destroyed. In recent years the problem of how to save and protect our forests has become so important that our national government has established the Dominion Forest Service and other organizations to help solve the problem. Over 10% of the total forest area in Canada has been permanently dedicated to forest production. Most provinces have also established departments of forestry, and many excellent private organizations are helping in the fight. Your part as an intelligent citizen will be to learn what can be done in the way of forest conservation and what you yourself can do; for, after all, saving our forests is a problem for every individual as well as for organizations.

How can we protect the forests we now have? Fires do the greatest amount of damage to our forests, and a great number of these fires are started by the carelessness of people. In 1940, 6,284 forest fires caused almost three million dollars' worth of damage to timber and property in Canada. One of the most important steps in saving our trees is the prevention of forest fires. Prevention of fires also saves many wild birds and mammals from being killed and preserves their homes. This

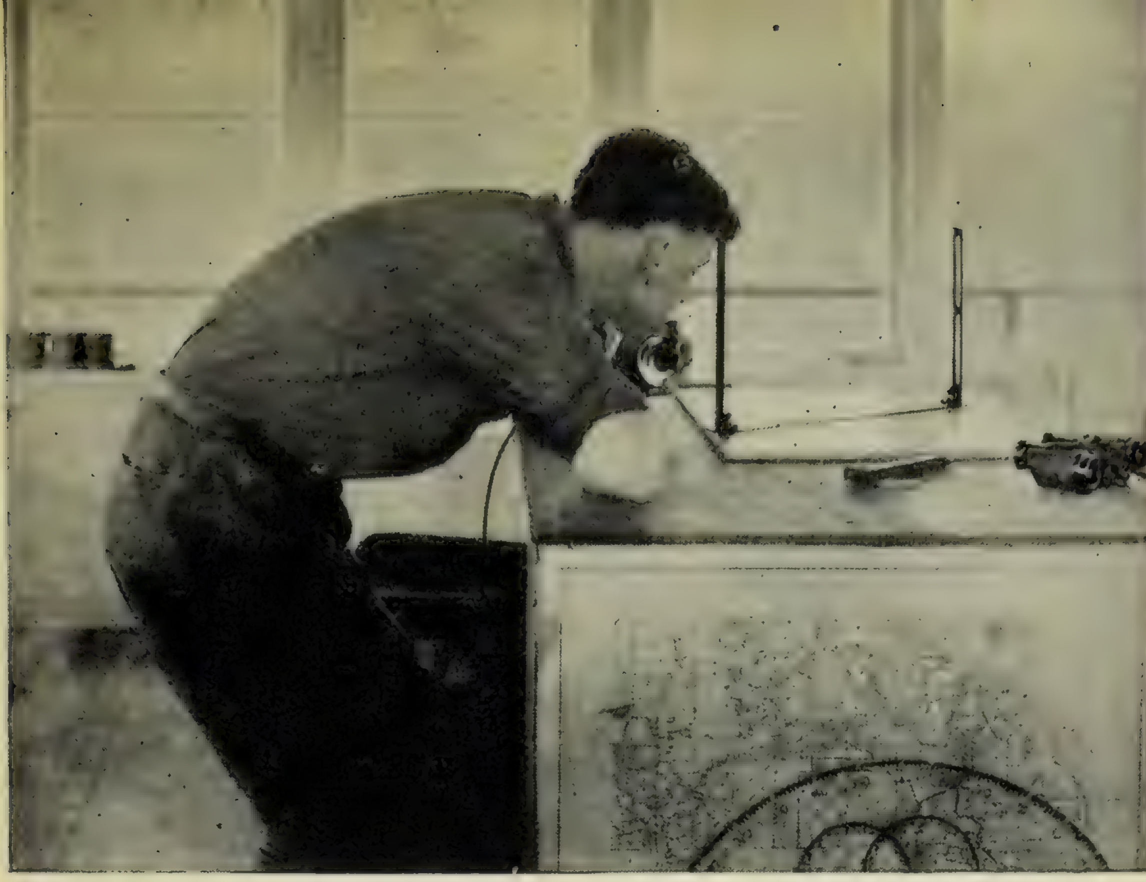

FIG. 527. The inside of a fire lookout station. When the lookout man sees smoke, he sights through a direction indicator and uses his maps to locate the fire exactly.

important task of protection from fires is largely in the hands of fire rangers. These rangers are given the power to enforce forest laws, and they are provided with special fire-fighting equipment. Fire stations are well supplied with fire-rakes, chemical fire-extinguishers, water pumps, and other equipment.

To help discover and locate fires, "lookout towers" are built. In each tower is an observer with binoculars, maps, direction indicators, and other instruments. When a fire is discovered, a message giving its exact position is sent by telephone or radio down to headquarters in the valley. Fire-fighters then "get on the job" to stop the fire before it spreads and gets out of control. Some fire-stations have sleeping and cooking quarters for the observers. Aeroplanes are used in some places for patrolling forests and finding forest fires. Planes fly regularly over their patrol regions, spot fires, and report them by means of radio. But waiting until a fire starts and then trying to put it out is dangerous business. So, to help control fires, *fire lanes* are made. To make a fire lane the timber is cut from a narrow strip, and the ground is plowed through regularly. Thus, if a fire starts in one part of a forest, it is prevented from spreading to other parts.

Forest conservation is being practised in still another way. Formerly, every usable tree was cut from the land as the logging crew went about its work. But the increasing scarcity of timber

FIG. 528. To cut trees in such a way as to preserve the forest for many years is a scientific procedure. These foresters are marking the adult trees they have selected to be cut down.

has now led to *selective cutting*. By this plan only a certain number of trees are cut for use at any single time. Other trees are left to mature, and new ones are planted as the supply is used. This keeps a steady supply of trees growing, and, if it is practised widely enough, we may be sure of having lumber in the future. Forestry specialists have learned that selective cutting not only keeps a reserve supply of trees, but it makes these trees grow faster. Thinning trees gives them room to grow.

Another way of protecting our forests is the study of tree diseases. Have you ever stopped to think how much trees are like people? In any large forest there are great numbers of healthy trees, just as in any large group of people there are many healthy people. However, there are always people who are sick. It is the same way in a forest; there are always trees that are diseased, weakened from old age, or injured. Trees suffer from disease epidemics just as people do. For example, about fifty years ago people began to plant nut trees that were imported from the Orient. With these trees there came into our country a disease known as the chestnut blight.

People paid little attention to this disease until most of the chestnut forests in the Lake Erie country and through the middle east of the United States showed signs of infection. The government became alarmed at the rapid loss of these valuable trees

and began experimenting to find ways of fighting the disease. Another disease, the white-pine blister rust, threatens our valuable white-pine forests.

In addition to diseases, insects take their toll from our forests. At the present time Canadian forests are suffering particularly from two insect outbreaks. The European spruce saw-fly attacks all kinds of spruce grown in Canada; by 1938 about 1200 square miles were heavily infested. Spruce is also attacked by the spruce budworm, a serious pest in northern Ontario, where it has killed large areas of spruce and balsam. A related insect attacks the Jack pine. In the Science Service, under the Department of Agriculture, government scientists are working on methods of controlling or curing tree diseases and getting rid of insect pests.

*Self-Testing Exercises.* 1. List methods of fighting forest fires. Try to add to your list other ways than those mentioned in your book.

2. What is selective cutting of trees? How does it work?

3. Do you think the government is justified in spending large amounts of money each year in the study and control of diseases of forest trees and of insect pests? Why do you think so?

*Problems to Solve.* 1. Find in newspapers and recent scientific magazines reports of (*a*) new uses for wood and (*b*) substitutes that have been found for wood.

2. Make a list of dominion, provincial, and private organizations that can be called on for aid in protecting our forests. After the name of each agency, try to list the kinds of help it offers.

3. Get a copy of the fire laws in regard to the forests of your province. Decide how you can help to carry them out.

4. Find out what diseases and insects are damaging trees in your locality. What measures are being taken to control them?

FIG. 529. White-pine blister rust (Ontario Forestry Branch)

Whole stands of forest were cut down in the early days, when trees were abundant and lumbering profitable. Today, in some places where trees once grew, are bald hill-sides, patches of gravel, fields of dust and sand. The removal of the trees has not only left such areas unproductive. It has left them dry. Streams that once ran in the shade have now been dried up by the burning sun. Tree-roots once held moisture in high ground, where it fed underground water courses and springs. Now the moisture drains down; wells have gone dry, and the hills are barren. This land could be reforested and made productive if the correct methods were used. What are some of the steps to be undertaken in the work of reforestation?

One of the most important things to study is the quality of soil. The soil must be analyzed to find what kinds of trees will grow best in the places where they are to be planted. For example, yellow poplar, white oak, sugar maple, and white ash grow best in fairly rich, moist loam and in clay-loam soils. Red pine, loblolly pine, and short-leaf pine grow best in dry, sandy soils. Black locust and white pine thrive in moist and sandy-loam soils. Sweet-gum, southern white cedar, and cypress grow best in semi-swampy soils. Very often mixed plantings are desirable. In this case the proper combinations must be made according to the locality and the type of soil.

Another thing to be considered is the size of seedlings to be planted. Most experiments show that no tree under six inches in height (not including the root system) should be planted. Other experiments show that reforestation projects are more successful when nursery stock rather than native seedlings is used. Young trees may be bought by the thousand very cheaply in most places.

Then comes the preparation of the land. Strangely enough, in most places scattered shrubby growth and older trees of poor quality should be removed before the new stock is planted. Planting may be done in the spring or fall, depending upon seasonal conditions, of course. The seedlings may be planted in furrows that have been broken with plows or in holes that are made with special tools. In some places they are planted in squares, and in others they are staggered. A good spacing is six feet in all directions from other seedlings.

Fig. 530. The tree nursery, like this one with its seed beds of one-year-old pines, makes possible many individual and local reforestation projects.

Experts say that the most damage to seedlings is done between the time they are taken from the nursery and the time they are planted. The tender root-hairs dry out and die, making it hard for the young trees to get a start. The seedlings should be *heeled-in* (put in trenches and covered with very moist soil) until they are put in their permanent places. Another caution experts give is in regard to the depth of planting. In general, seedlings should be planted about one-half inch deeper than they grew in the nursery. The roots should be spread out in a normal position, but should never be curved upward. Finally, the soil must be packed tightly to fill up air-pockets that might have been left about the roots. Then the trees are ready to do their part in the reforestation project.

The national and provincial governments and other agencies are doing much for you and other citizens in restoring our forests, establishing natural parks and camping grounds, maintaining fire patrols, and providing museum exhibits of forest products. What can you do to help? You have already been doing something very important. You have been learning about conservation. The next step is to put what you have learned into practice in so far as you are able. When you take hikes and cook meals in the woods, you can prevent fires by obeying the fire laws and by seeing that others obey them. You can help plant trees where they are needed, and you can keep informed about what is happening to our forests. You can insist that our provincial and national law-makers vote right on laws that we need to save our forests.

FIG. 531. Before a woodsman builds a camp fire, he clears a place of all grass, pine needles, and trash, digs a hole, and in it builds the fire. Are we as careful?

FIG. 532. Before leaving a camp fire, even for a short time, you should first pour plenty of water over the fire and then cover it with earth.

*Self-Testing Exercises.* 1. Make a list of important things to know in planning to plant trees on a large scale.

2. What can you do to help preserve our forests?

*Problems to Solve.* 1. Talk with farmers, lumbermen, and other people in your community to find out (*a*) what kinds of trees are considered of most value, (*b*) which are of least value, (*c*) which are most plentiful, (*d*) which are scarce, and (*e*) what kinds of trees grow best.

2. Are any reforestation projects being carried on near you? If so, visit them to find out what methods are being used. Note carefully the kinds of trees that are being planted, when the planting is done, the spacing of seedlings, the depth of planting, and other important factors.

3. Get a map of your community and make a survey to find where tree planting should be done. Color these places in a special way on your map. This is a good class project.

## Looking Back at Unit 20

1. Copy the sub-problems of this unit, and write a few sentences to answer the main question asked in each sub-problem. If several ways of solving a particular problem are given, list these ways. This exercise is planned to give you a picture of conservation as it is discussed in this unit.

2. Show in any way which seems best to you that you know the meanings of the following words or terms:

| | | |
|---|---|---|
| *contour farming* | *strip cropping* | *good sportsmanship* |
| *re-pressuring* | *cracking oil* | *selective cutting* |
| *clean farming* | *terracing* | *fuel oil* |

## Additional Exercises

1. Make a collection of the wood of different kinds of trees that grow in your locality and elsewhere. Cut the specimens in four-by-six-inch sizes and sandpaper them to bring out the natural grain of the wood. Mount them for display in your classroom or school museum. Be sure to label each specimen carefully.

2. Make a large graph to show what becomes of the wood from an average tree that is used for lumber. Use the figures given on page 705.

3. Write to the Dominion Department of Agriculture, your provincial Department of Agriculture, and other sources for lists of bulletins and free material on conservation. Secure as many different kinds of these as possible for your school library. They will help you in any further work you want to do on conservation.

4. Make a collection of coal and products that are made from coal. Do the same for petroleum. Mount these products so that they may be used for study in class.

5. Make plans for a bird shelter and feeding station. State what kinds of birds you would expect to use it.

6. With your classmates visit your schoolground, a near-by park, or a woodland and plan a bird sanctuary. Make a map of the place and locate the best places to put bird houses, feeding stations, and for planting wild plants to be used as food by the birds. If possible, put your plan into action by proposing it to the Boy Scouts, Girl Guides, or other organizations to which you belong. Ask your teacher, your scoutmaster, and your parents to help with your project.

7. How is the study of animal diseases a part of conservation? Have your teacher write to the Science Service, the Department of Agriculture, Ottawa, for information about this study.

8. Make a special study of the conservation of wild flowers. What is being done in your province? Ask a member of the Federation of Ontario Naturalists for information, and form your own naturalists' club.

9. Read in government bulletins and other reference books to find out how experts learn the feeding habits of animals.

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Butler, O. M. *Rangers of the Shield.* American Forestry Association.

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# Science Words

HERE IS A LIST OF THE IMPORTANT SCIENCE WORDS in this book, with the pronunciation and the meaning of each one. The marked letters in parentheses are sounded according to the letters in the following list of sample words. The accented syllable is marked ′. This lighter mark ′ shows a lighter accent.

| | | |
|---|---|---|
| a at, can | ē be, equal | o̤ actor, second |
| ā came, face | ė her, certain | oi oil, point |
| ä far, father | e̤ towel, prudent | ou out, found |
| â all, ball | i it, pin | s̮ nausea |
| ȧ ask | ī line, mine | t̮ picture |
| ã care, dare | o on, not | u up, but |
| a̤ alone, company | ō more, open | ū use, pure |
| ä̤ beggar, opera | ö to, move | u̇ put, full |
| e end, bend | ô off, song | ṳ̄ nature |

A single dot under ā, ē, ō, ö, or ū means that the sound is a little shorter and lighter, as in cot′tạ̄ge, rẹ̄-dūce′, gas′ọ̄-line, in′tọ̈, ụ̄nī′ted.

**ab do men** (ab-dō′men or ab′dọ̄-men): 1. the lower part of the human body. 2. the last of the three parts of an insect's body.
**a ce tic** (a-sē′tik or a-set′ik) **acid**: a colorless liquid with a sour or biting taste, a compound of hydrogen, oxygen, and carbon.
**a cid** (as′id): the name given to a class of substances generally sour or bitter to the taste, soluble in water, and that turn blue litmus to red.
**a cous ti cal** (ạ-kös′ti-kạl) **engineer**: a person who plans the control of sounds in buildings, etc.
**ad e noid** (ad′ẹ-noid): the glandular tissue between the back of the nose and the throat.
**ad he sion** (ad-hē′zhọn): the sticking together of two different substances.
**ad o les cent** (ad-ọ̄-les′ẹnt): 1. growing up to manhood or womanhood. 2. a person from about 13 to 18.
**aer i al** (ãr′i-ạl): the wires in the air for receiving and sending radio waves.
**al gae,** singular **al ga** (al′jē, al′gä̤): water plants that can make their own food. Most seaweeds are algae.
**al i men ta ry** (al-i-men′tạ-ri) **canal**: the parts of the body through which the food passes while it is being digested.
**al ka li** (al′kạ-lī or al′kạ-li): the name given to various substances characterized by their peculiar taste, by their changing red litmus to blue, and by their forming salts when combined with acids.
**al loy** (ạ-loi′): a mixture of two or more metals.
**al ter nat ing** (âl′tėr-nā-ting) **current**: electric current that flows back and forth in a conductor instead of flowing always in the same direction.
**al tim e ter** (al-tim′e-tėr): an instrument that measures height above sea-level.

**a lu mi num** (a-lū′mi-num): a very light, silver-white metallic element that does not tarnish easily. It is a good conductor of heat and electricity.

**a me ba**, plural **a me bae** or **a me bas** (a-mē′ạ̈, a-mē′bē or a-mē′bạ̈z): a very small water animal.

**am me ter** (am′ė-tėr or am′mē′tėr): an instrument that measures the size of electric currents in amperes.

**am pere** (am′pēr): the unit for measuring the rate at which an electrical current flows through a wire.

**am pli fi ca tion** (am′pli-fi-kā′shọn): enlargement or extension.

**am pli fy** (am′pli-fī): enlarge or extend.

**a nal y sis** (ạ-nal′i-sis): the separating of anything into its various parts.

**an a lyt i cal** (an-ạ-lit′i-kạl) **balance**: an extremely delicate pair of scales for weighing things, used to find out the material of which things are made.

**an e mom e ter** (an-ẹ̄-mom′e-tėr): an instrument that shows the speed of the wind in miles per hour.

**an e roid** (an′ẹ-roid) **barometer**: a barometer worked by air pressing against the sides of an air-tight metal box from which the air has been pumped out.

**an aes thet ic** (an-es-thet′ik): a material that is used by doctors so that patients will feel no pain.

**angle of in ci dence** (in′si-dẹns): the angle between a ray of light that strikes a surface and the normal (perpendicular) to the surface at that point.

**angle of re flec tion** (rẹ̄-flek′shọn): the angle between a ray of light reflected from a surface and the normal (perpendicular) to the surface at that point.

**an i line** (an′i-lin): a colorless liquid, a compound of carbon, nitrogen, and hydrogen, obtained from coal tar.

**an thra cite** (an′thrạ-sīt) **coal**: hard coal that burns with very little smoke and flame.

**an ti bod ies** (an′ti-bod-iz): chemicals produced in the blood of an animal or man that help overcome germs or their poisons.

**an ti sep tic** (an-ti-sep′tik): substance that kills or prevents the growth of germs.

**an ti tox in** (an-ti-tok′sin): a substance formed in the body that acts against the poisons produced by germs.

**a nus** (ā′nus): the opening at the end of the alimentary canal, through which waste material and undigested food pass.

**a or ta** (ā-ôr′tạ̈): the main artery that carries the blood from the left side of the heart to all parts of the body except the lungs.

**a que duct** (ak′wẹ̄-dukt): a channel or pipe to bring water from a distance.

**Ar chi me des** (är-ki-mē′dēz): a famous Greek scientist (287?-212 B.C.)

**arc lamp**: a lamp in which an electric arc is the source of light.

**ar ma ture** (är′mạ-ṭūr): 1. piece of soft iron arranged to be attracted by the poles of a magnet. 2. coils of wire that revolve in the magnetic field of a generator to produce electric current. 3. revolving part of an electric motor.

**ar te ry** (är′tẹ-ri): a blood vessel that carries blood from the heart.

**ar te sian** (är-tē′zhạn) **well**: a well from which water flows with considerable force because the water is under pressure.

**as tig ma tism** (as-tig′mạ-tizm): an eye defect that prevents light rays from coming to a focus at a single point on the retina, thus causing a blurred image.

**as trol o gy** (as-trol′ọ̄-ji): a false science that claims to determine the influence of the stars and planets on persons, events, etc.

**as tron o my** (as-tron′ọ̄-mi): the science of the sun, moon, planets, stars, etc.

**at mo sphere** (at′mọs-fēr): the air that surrounds the earth.

**at mo spher ic** (at-mọs-fer′ik) **pressure**: the force with which the atmosphere presses on things. Atmospheric pressure at sea-level is about 15 pounds per square inch.

**at om** (at′ọm): the smallest particle of which matter consists. Atoms make up molecules, next larger particles.

**au di to ry** (â′di-tọ-ri): having to do with hearing.
**au ri cle** (â′ri-kl): one of the two upper chambers of the heart.
**au to gi ro** (â-tọ-jī′rō): an aeroplane whose large horizontal propeller enables it to rise or descend almost vertically, and to remain almost stationary in the air.
**ax is** (ak′sis): real or imaginary straight line around which an object revolves.

**Bab bitt** (bab′it) **metal:** a metal made of tin and antimony.
**ba cil lus,** plural **ba cil li** (ba-sil′us, ba-sil′ī): any of the cylinder-shaped bacteria.
**bac te ri a,** singular **bac te ri um** (bak-tē′ri-ạ̈, bak-tē′ri-um): very tiny living plants, some of which cause diseases, and others of which are useful.
**bac te ri ol o gist** (bak-tē-ri-ol′ọ-jist): a scientist who studies bacteria.
**bar o graph** (bar′ọ-gråf): a recording barometer.
**ba rom e ter** (bạ-rom′e-tėr): an instrument for measuring air-pressure.
**bat tery** (bat′ėr-i): a set of two or more electric cells that produce electric current.
**ber i-ber i** (ber′i-ber′i): a disease caused by a lack of a certain vitamin.
**bi ceps** (bī′seps): the large muscle in the front part of the upper arm.
**bile** (bīl): a bitter yellowish liquid secreted by the liver. Bile aids digestion.
**bi ol o gist** (bī-ol′ọ-jist): a scientist who knows much about biology.
**bi ol o gy** (bī-ol′ọ-ji): the science of life or living things.
**bi tu mi nous** (bi-tū′mi-nus) **coal:** soft, easily crumbled coal that burns with much smoke and flame.
**block and tackle:** a combination of pulleys and rope used to lift weights or otherwise exert a great force.
**boiling point:** the temperature at which a liquid changes to a gas.
**brine:** very salty water.
**bron chi al** (brong′ki-ạl) **tubes:** the two large, main branches of the windpipe and the small branches of each of these.
**brush:** a strip of metal or block of carbon that carries electric current to or from the armature.
**buoy an cy** (boi′ạn-si or böi′ạn-si): the upward pressure exerted by a liquid or a gas on a body.

**cal o rie** (kal′ọ-ri): a unit for measuring the amount of heat: 1. the amount of heat required to raise the temperature of one gram of water one degree centigrade. 2. the amount of heat required to raise the temperature of one kilogram of water one degree centigrade or to warm one pound of water about four degrees Fahrenheit.
**cap il la ry** (kap′i-lạ̄-ri): a tiny blood tube that connects an artery with a vein.
**car bo hy drate** (kär-bọ-hī′drāt): the class of food substances to which sugar and starch belong.
**car bon** (kär′bọn): the most abundant element in coal and charcoal.
**carbon di ox ide** (dī-ok′sīd or dī-ok′sid): a heavy, colorless, odorless gas made up of carbon and oxygen.
**carbon tet ra chlo ride** (tet-rạ-klō′rīd): a liquid which changes at low temperature to a vapor five times heavier than air.
**car bu ret or** ((kär′bụ̄-ret-ọr): a device for vaporizing gasoline and mixing it with air in a gasoline engine.
**car niv o rous** (kär-niv′ọ-rus): refers to animals that eat meat.
**car ti lage** (kär′ti-lạ̄j): gristle; a firm, elastic, flexible substance forming parts of a skeleton.
**cel a nese** (sel-ạ-nēz′): an artificial fibre manufactured from cotton and resembling silk in appearance.
**cell:** 1. one of the small sections or units of which all animals and plants are made and which is formed of a small amount of living matter, called protoplasm. 2. a device that produces an electric current by chemical action.

**cen ti grade** (sen′ti-grād): indicates the scale on a thermometer that has 0° for the temperature at which water freezes and 100° for the temperature at which water boils. To change centigrade to Fahrenheit, multiply by $\frac{9}{5}$ and add 32.

**cen trif u gal** (sen-trif′ū-gal) **force:** the force that makes whirling things fly away from the centre.

**change of state:** change of a material to a solid, liquid, or gas. Freezing, melting, and boiling cause a change of state.

**charge:** give an object an electric charge; supply an object, such as a storage battery, with electrical energy by passing an electric current through it.

**chemical change:** the change that results in a new material or materials with different characteristics than the original material.

**chemical energy:** energy released by a chemical change.

**chemical e qua tion** (ē-kwā′zhon or ē-kwā′shon): a chemical "sentence" that shows the materials used and the materials produced during a chemical change. A chemical equation is usually written with symbols, as $Hg + O \rightarrow HgO$.

**chem ist** (kem′ist): a scientist who knows much about chemistry.

**chem is try** (kem′is-tri): the science of the composition of materials and the laws that govern their changes when they combine with other materials.

**chlo rine** (klō′rēn or klō′rin): an element usually in the form of a greenish-yellow, poisonous, suffocating gas.

**chlo ro phyll** (klō′rō-fil): the green coloring matter of plants.

**chlo ro plast** (klō′rō-plast): a tiny body that contains chlorophyll.

**chol e ra** (kol′e-rä): a serious disease of the digestive organs.

**chro nom e ter** (krō-nom′e-tėr): a very accurate clock.

**cil i a** (sil′i-ä): microscopic living, moving hairs, such as those that cover the linings of the breathing passages.

**cir cuit** (sėr′kit): the complete path of an electric current.

**cir cu la to ry** (sėr′kū-lā-tō-ri) **system:** the blood system.

**cir rus** (sir′us): tufted, thread-like or feather-like clouds.

**clin ic** (klin′ik): a place for medical instruction and treatment.

**clin i cal** (klin′i-kal) **thermometer:** an instrument used to measure body temperature.

**coc cus,** plural **coc ci** (kok′us, kok′sī): any of the ball-shaped bacteria.

**coch le a** (kok′lē-ä): the inner ear, shaped like a snail's shell and filled with liquid.

**co coon** (ko-kön′): a silky case or shell made by worms and caterpillars to live in while they are turning into moths or butterflies.

**co he sion** (kō-hē′zhon): the sticking together of the molecules of a substance.

**col o ny** (kol′ō-ni): a group of plants or animals of the same kind living or growing together.

**combination:** the kind of chemical change that results in the joining together of two or more elements to form a new compound.

**com bine** (kom-bīn′): join together to form a new compound.

**com bus ti ble** (kom-bus′ti-bl): capable of taking fire and burning.

**com bus tion** (kom-bus′chon): the combination of a substance with oxygen, generally so rapid as to produce heat and light.

**com et** (kom′et): a heavenly body that travels in a long, loop-shaped orbit around the sun. Some comets have long tails.

**com mu ta tor** (kom′ū-tā-tor): a device for reversing an electric current.

**com po si tion** (kom-pō-zish′on): the make-up of anything.

**com pound** (kom′pound): material that can be divided into two or more elements; material formed by chemical combination of two or more elements.

**con cave** (kon′kāv): curved like the inside of a circle or sphere.

**con den sa tion** (kon-den-sā′shon): 1. the change of a gas to a liquid. 2. the part of a sound wave in which the air molecules are pressed together.

**con dense** (kọn-dens′): change from a gas to a liquid.
**con duc tion** (kọn-duk′shọn): the movement of heat from molecule to molecule through a material.
**con duc tor** (kọn-duk′tọr): a material through which heat, electricity, or sound can pass easily.
**con duit** (kon′dit): a channel or pipe for the flow of liquids from one place to another; a pipe, tube, or underground passage for electric wires.
**con glom er ate** (kọn-glom′ẹ-rāt): rock made of pieces of gravel held together by crystals of dissolved minerals and by great pressure.
**con ser va tion** (kon-sėr-vā′shọn): the prevention of waste of natural resources.
**con stel la tion** (kon-ste-lā′shọn): a group of stars.
**con ta gious** (kọn-tā′jus): easily spread from one person to another.
**con tour** (kon′tör): the shape of the surface of the land.
**con vec tion** (kọn-vek′shọn): the movement of heat in a liquid or gas by means of currents from hotter to colder bodies.
**con vex** (kon′veks): curved like the outside of a circle or sphere.
**Co per ni cus** (kọ̄-pėr′ni-kus): a Polish astronomer who discovered that the earth and the planets move about the sun (1473-1543).
**cor ne a** (kôr′nẹ̄-ạ): the transparent outside covering of the eyeball.
**cor pus cle** (kôr′pus-l): a cell, either red or white, in the blood. The corpuscles are the solid part of the blood.
**crude oil**: raw petroleum as it comes from the earth.
**cul ture** (kul′tụ̄r): some jelly or liquid in which a certain kind of bacteria (or other organism) is growing for some purpose.
**cu mu lus** (kū′mụ̄-lus): a dome-shaped cloud with a flat base.
**cur vi lin e ar** (kėr-vi-lin′ẹ̄-ạ̈r): made up of curved lines.
**cy cle** (sī′kl): the series of strokes of a piston in the cylinder of an engine.
**cy clone** (sī′klōn): an atmospheric condition of low pressure around which winds revolve and blow inward. The low-pressure centre is constantly moving.
**cyl in der** (sil′in-dėr): the part of an engine or other device in which a piston slides back and forth.

**dec i bel** (des′i-bel): the unit for measuring the loudness of sound.
**de com pose** (dē-kọm-pōz′): separate a chemical compound into elements or simpler compounds.
**de com po si tion** (dē-kom-pọ̄-zish′ọn): the kind of chemical change that separates a compound into other compounds or the elements that compose it.
**den si ty** (den′si-ti): the amount of material in a unit volume of a substance, such as the number of pounds of wood in a cubic foot.
**de pend ent** (dẹ̄-pen′dẹnt) **plant**: a plant that does not make its own food, but lives on other living things or on dead things.
**dep o si tion** (dep-ọ̄-zish′ọn): the dropping or laying down of a material.
**der mis** (dėr′mis): the layer of skin beneath the epidermis or outer layer.
**dew point**: the temperature of the air at which dew begins to form.
**di ag no sis** (dī-ag-nō′sis): deciding what disease a person has by studying him.
**di a phragm** (dī′ạ-fram): a thin dividing partition.
**di as tro phism** (dī-as′trọ̄-fizm): the rising and falling of the earth's surface and other changes in the positions of rocks.
**dif fer en tial** (dif-ẹ-ren′shạl): an arrangement of gears that allows for the difference in speed of the two driving wheels, as in turning a corner.
**dif fused** (di-fūzd′) **light**: reflected light that is scattered.
**dif fu sion** (di-fū′zhọn): the moving of a material from one place to another by the bouncing of the separate molecules.
**di gest** (di-jest′ or dī-jest′): change food in the stomach and intestines so that it will dissolve and the body can use it.
**di ges tion** (di-jes′chọn): changing foods so that they can be used by the body.

**di ges tive** (di-jes′tiv) **system:** the system of the body in which food is changed into substances that the body can absorb.

**direct current:** electric current that flows in one direction only.

**dis in fect ant** (dis-in-fek′tạnt): a substance that destroys disease-producing germs, but is not used on the human body.

**dis solve** (di-zolv′): change a solid to liquid form by mixing it with a liquid.

**dis til** (dis-til′): change a liquid to a gas by heating and then change the gas back into a liquid by cooling it.

**dis til la tion** (dis-ti-lā′shọn): the process of changing a liquid to a gas by heating and then changing the gas back to a liquid by cooling it.

**dis trib u tor** (dis-trib′ū-tọr): a device in a gasoline engine that sends a current to each spark plug at the proper time.

**dry cell:** a cell for producing electric current, having zinc and carbon electrodes and a paste moistened with ammonium chloride as the active chemical.

**duct:** a tube or canal for carrying liquid.

**dy na mo** (dī′nạ-mō): an apparatus for producing electric current; generator.

**ec cen tric** (ek-sen′trik): circular device that rotates about a point not its centre, used on machines for changing circular motion into back-and-forth motion.

**e clipse** (ẹ-klips′): passing from sight because light is cut off.

**e lec trode** (ẹ-lek′trōd): either of the two poles, or terminals, of a battery or any similar electrical device.

**e lec trol y sis** (ē-lek-trol′i-sis): the use of an electric current to decompose a melted or dissolved chemical compound into its elements.

**e lec tro lyte** (ẹ-lek′trọ-līt): a melted or dissolved compound that will conduct an electric current.

**elec tro mag net** (ẹ-lek′trọ-mag′net): a piece of soft iron made into a magnet by an electric current in a wire coiled around the iron.

**e lec tron** (ẹ-lek′tron): tiny particle containing a negative charge of electricity.

**e lec tro plat ing** (ẹ-lek′trọ-plā-ting): coating an object with metal by using electric current and an electrolyte.

**el e ment** (el′ẹ-mẹnt): material that cannot be separated into other materials.

**en do crine** (en′dọ-krīn or en′dọ-krin): pertaining to certain glands in the body that put their secretions into the blood.

**en er gy** (en′ėr-ji): the power to make matter move or change.

**ep i dem ic** (ep-i-dem′ik): rapid spreading of a disease so that many people or animals have it at once.

**ep i der mis** (ep-i-dėr′mis): 1. the outer layer of cells in plants. 2. the outer skin of animals.

**ep i glot tis** (ep-i-glot′is): a flap that covers the top of the windpipe during swallowing, so that food does not get into the windpipe.

**e rode** (ẹ-rōd′): eat away or wear away.

**e ro sion** (ẹ-rō′zhọn): eating away or wearing away.

**e soph a gus** (ẹ-sof′ạ-gus): food passage from the mouth to the stomach; gullet.

**Eu sta chi an** (ū-stā′ki-ạn) **tube:** a tube that leads from the back part of the mouth to the middle ear.

**e vap o rate** (ẹ-vap′ọ-rāt): change to a gas.

**e vap o ra tion** (ẹ-vap-ọ-rā′shọn): the change of a liquid to a gas.

**ex crete** (eks-krēt′): separate and expel waste matter.

**ex per i ment** (eks-per′i-mẹnt for noun, eks-per′i-ment for verb): test to find out whether something is correct or not.

**Fah ren heit** (fä′rẹn-hīt or far′ẹn-hīt): indicates a scale on a thermometer that has 32° for the temperature at which water freezes and 212° for the temperature at which water boils. To change Fahrenheit to centigrade, subtract 32 and multiply by $\frac{5}{9}$.

**fat:** a food material made of carbon, hydrogen, and oxygen, that the body uses for energy and storage.
**fault:** a break in rocks that allows them to move past each other.
**feld spar** (feld′spär): a dull, somewhat transparent mineral found in granite.
**fer men ta tion** (fėr-men-tā′shọn): a chemical change in which sugar is turned to alcohol and carbon-dioxide gas.
**fi brous** (fī′brus) **roots:** roots of nearly the same size that make up the root system of plants like corn, rye, and wheat.
**field magnet:** an electromagnet used in a generator or motor to make a strong electric field.
**fil a ment** (fil′ạ-mẹnt): the thread-like wires in an electric light-bulb that glow.
**fil tra tion** (fil-trā′shọn): a method of removing impurities from a liquid by running it through some material through which the impurities cannot pass.
**fluc tu at ing** (fluk′tū-ā-ting) **current:** current varying in strength.
**flu id** (flö′id): any substance, either gas or liquid, that will flow.
**flu or es cent** (flö-ọr-es′ẹnt) **lamp:** a lamp without a filament that produces light from special materials coating the inside of the glass tubes.
**fo cus** (fō′kus): 1. place a lens in such a position that the light rays coming through it make a clear image. 2. the point at which rays of light, heat, etc., meet after being reflected or refracted.
**foot-candle:** the unit for measuring the brightness of illumination. It is equal to the illumination provided by a standard candle at a distance of one foot.
**foot-pound:** a unit for measuring work. It is equal to the work done when a force of one pound is moved through a distance of one foot.
**force** (fōrs): a push or pull that tends to set a body in motion, or to stop a body that is already moving, or to change the direction in which a body is moving.
**force-arm:** the distance from the force to the fulcrum in a lever.
**for mu la** (fôr′mū-lạ): an expression or abbreviation showing by symbols the chemical elements of a compound. The formula for water is $H_2O$.
**fos sil** (fos′il): the hardened remains or trace of an animal or plant.
**freezing point:** the temperature at which a liquid changes to a solid.
**fre quen cy** (frē′kwẹn-si): 1. the number of vibrations per second of the source of a sound. 2. the number of waves per second sent out in radio.
**fric tion** (frik′shọn): the rubbing of one thing against another; resistance to motion of surfaces that touch each other.
**fric tion al** (frik′shọn-al) **electricity:** electric charges produced by rubbing one material on another.
**ful crum** (ful′krum): the place where a lever is rested or supported.
**fu mi ga tion** (fū-mi-gā′shọn): exposing to smoke or fumes, as in disinfecting.
**func tion** (fungk′shọn): proper work of anything, as, the function of the heart.
**fun gus,** plural **fun gi** (fung′gus, fun′jī): a plant without chlorophyll. Mushrooms, molds, and mildews are fungi.
**fuse** (fūz): a part of an electric circuit that will melt and break the circuit if the current gets dangerously large.

**gal ax y** (gal′ạk-si): an arrangement of countless stars in a group.
**Gal i le o** (gal-i-lē′ō): a famous Italian scientist (1564-1642).
**gall-blad der** (gâl′blad′ėr): the sac that receives the gall or bile from the liver.
**gal va nom e ter** (gal-va-nom′e-tėr): an instrument for determining the presence, size, and direction of an electric current.
**gas:** the form of matter that has no definite size or shape.
**gas tric** (gas′trik) **juice:** the digestive liquid produced by glands in the wall of the stomach.
**gear:** a wheel having teeth that fit into the teeth in another wheel.
**gen er a tor** (jen′ẹ-rā-tọr): an apparatus for producing electric current; a machine for changing mechanical energy into the energy of an electric current.

**ge ol o gist** (jẹ̄-ol′ọ̄-jist): a scientist who studies the structure and changes of the earth.
**germ** (jėrm): a one-celled, microscopic plant or animal that causes disease.
**ger mi cide** (jėr′mi-sīd): something that kills germs.
**gey ser** (gī′zėr or gī′sėr): a hot spring which sends up at frequent intervals a jet of hot water or steam.
**gla cial** (glā′shạl) **drift**: the material transported by glaciers.
**gla cier** (glā′shėr): a mass of ice formed by pressure from snow on high ground, which moves slowly outward and downward.
**gland**: a group of cells that makes and gives out some substance.
**glot tis** (glot′is): the opening at the upper end of the windpipe.
**goitre** (goi′tėr): enlargement of the thyroid gland caused by a lack of iodine.
**gram**: the unit of weight in the metric system; about $\frac{1}{29}$ of an ounce.
**graph ite** (graf′īt): a soft, black, greasy form of carbon.
**grav i ta tion** (grav-i-tā′shọn): the fact that the earth pulls all things toward it and that the sun, moon, stars, and planets do the same; the force or pull that makes bodies in the universe tend to move toward one another.
**grav i ty** (grav′i-ti): the force that draws all bodies toward the centre of the earth and thus gives them weight.
**gris tle** (gris′l): hard elastic tissue; cartilage.
**guard cell**: one of a pair of tiny bean-shaped cells that open and close the stomata of a leaf.

**heating element**: the part of an electrical heating device that gets hot.
**hel i cop ter** (hel-i-kop′tėr): aeroplane whose big horizontal propeller enables it to rise or descend almost vertically, and to remain almost stationary in the air.
**he li um** (hē′li-um): one of the elements, a light gas, discovered first in the sun by use of the spectroscope and later in the earth.
**hem o glo bin** (hem-ọ̄-glō′bin): the red substance in the blood.
**her biv o rous** (hėr-biv′ọ̄-rus): refers to animals that eat plants.
**high-frequency alternating currents**: the currents of electricity sending out radio waves to the surrounding space.
**horse-power** (hôrs′pou′ėr): a unit for measuring the rate at which a machine can do work. It is equal to the power necessary to do 550 foot-pounds of work in a second.
**host** (hōst): the living thing upon which a parasite lives and from which it usually obtains its nourishment.
**hu mid i ty** (hū-mid′i-ti): the amount of moisture in the air.
**hu mus** (hū′mus): the part of soil that is made from decayed and decaying plant or animal material.
**hy drau lic** (hī-drâ′lik): having to do with water.
**hy dro car bon** (hī-drọ̄-kär′bọn): any compound containing only hydrogen and carbon.
**hy drom e ter** (hī-drom′e-tėr): an instrument for finding the densities of liquids.
**hy dro sphere** (hī′drọ̄-sfēr): the name given to all the water on the earth taken together.
**hy giene** (hī′jēn or hī′ji-ēn): the rules of health; the science of keeping well.
**hy phae**, singular **hy pha** (hī′fē, hī′fạ): tiny thread-like tubes of a plant, like bread mold, that get food for the plant.
**hy poth e sis** (hī-poth′e-sis or hi-poth′e-sis): the best solution that can be thought of for a problem at any given time; a statement that cannot be proved to be true, but that offers the best explanation for the known facts.

**ig ne ous** (ig′nẹ̄-us) **rock**: rock that has melted and hardened.
**im age** (im′ạj): a picture of an object such as is formed by a light that passes through a lens or is reflected by a mirror.

**im mune** (i-mūn′): not susceptible. A person who is immune to a contagious disease does not take it even though he gets some of the germs in his body.
**im mu ni ty** (i-mū′ni-ti): freedom from or resistance to disease.
**im per vi ous** (im-pėr′vi-us): not letting a thing pass through.
**in can des cent** (in-kan-des′ent): glowing with heat.
**inclined plane**: sloping surface.
**in com bus ti ble** (in-kom-bus′ti-bl): not capable of being burned.
**in cu ba tion** (in-kū-bā′shon) **period**: the time between infection and the appearance of the symptoms of a disease.
**in duc tion** (in-duk′shon) **coil**: a small transformer consisting of a primary coil wound with insulated wire and a secondary coil fitted over the primary, wound with many thousand turns of small insulated wire.
**in er tia** (in-ėr′shä or in-ėr′shiä): the tendency of all objects to stay still if still, or, if moving, to go on moving in the same direction, unless acted on by some outside force.
**in fect** (in-fekt′): cause disease by filling with germs.
**in fec tion** (in-fek′shon): taking or getting germs into the body.
**in fec tious** (in-fek′shus) **disease**: disease caused by growth of germs in the body. Many infectious diseases can be spread from one person to another.
**in flam ma tion** (in-fla-mā′shon): a diseased condition of some part of the body, causing heat, redness, swelling, and pain.
**in oc u late** (in-ok-ū-lāt): infect a person or animal with germs which will cause a mild form of a disease to prevent his taking the regular disease.
**in su la tor** (in′sū-lā-tor): a material that prevents the passage of electricity or heat; non-conductor.
**in ter nal-com bus tion** (in-tėr′nal-kom-bus′chon) **engine**: an engine that burns fuel inside itself.
**in tes ti nal** (in-tes′ti-nal) **juice**: a digestive juice secreted by glands in the small intestine.
**in tes tine** (in-tes′tin): a part of the alimentary canal.
**i on** (ī′on): one of the charged particles into which some materials are broken up when they are dissolved; a charged particle in the air.
**i ris** (ī′ris): the colored part of the eye around the pupil.
**i sin glass** (ī′zing-glȧs): mica; a mineral that splits into thin, partly transparent layers.
**i so bar** (ī′sō-bär): a line on a weather map connecting places having the same atmospheric pressure (barometer reading).
**i so therm** (ī′sō-thėrm): a line on a weather map connecting places that have the same temperature.

**jack**: a machine for lifting heavy weights short distances.
**jackscrew**: a jack for raising weights, operated by a screw.

**kid ney** (kid′ni): one of the pair of organs that separate waste matter and water from the blood and pass it off through the bladder in liquid form.
**kil o cy cle** (kil′ō-sī-kl): a unit equal to 1000 cycles, used especially in radio for measuring the frequency of electric waves.
**kil o gram** (kil′ō-gram): a unit of weight in the metric system equal to 1000 grams or about 2.2 pounds.
**kil o watt** (kil′ō-wot): a unit of electric power equal to 1000 watts.
**kilowatt-hour**: 1000 watt-hours of electric energy.
**kin dling** (kin′dling) **temperature**: the temperature at which a material begins to burn.
**ki net ic** (ki-net′ik or kī-net′ik) **energy**: the form of energy that all moving objects have.
**knot** (not): a unit of speed equal to one nautical mile (6080.27 ft.) per hour.

**lac te al** (lak′tẹ-ạl): one of the tiny tubes that takes a milky fluid containing digested fats from the small intestine to be mixed with the blood.
**lar va,** plural **lar vae** (lär′vạ, lär′vē): the grub or caterpillar of an insect from the time of leaving the egg until it becomes a pupa.
**lar ynx** (lar′ingks): the upper end of the windpipe, where the vocal chords are.
**lat i tude** (lat′i-tūd): distance north or south of the equator, measured in degrees.
**la va** (lä′vạ): melted rock that flows from volcanoes or through great cracks in the earth.
**lead per ox ide** (led pėr-ok′sīd or pėr-ok′sid): the material used for the positive electrodes of a storage battery.
**leg ume** (leg′ūm or lė-gūm′): plant like beans, peas, alfalfa, and clover.
**lens** (lenz): a glass or glass-like material so made as to bring closer together or send wider apart the rays of light passing through it.
**lev er** (lev′ėr or lē′vėr): bar working on a pivot or support, called a fulcrum.
**lig a ment** (lig′ạ-mẹnt): a band of strong tissue that connects bones or holds parts of the body in place.
**liquid**: the form of matter that has a definite size but no definite shape.
**lith o sphere** (lith′ọ̄-sfēr): the main solid part of the earth.
**lit mus** (lit′mus): a blue coloring matter, used to make litmus paper for testing purposes, since it is turned red by acids and restored to blue by alkalies.
**liv er** (liv′ėr): the large reddish-brown organ in people and animals that makes bile and aids in the digestion of food.
**loam** (lōm): rich soil made up of clay, sand, and decayed plant materials in approximately equal parts.
**lon gi tude** (lon′ji-tūd): distance east or west of the prime meridian at Greenwich, England, measured in degrees.
**lu bri cate** (lū′bri-kāt): make smooth, slippery, and easy to work by putting on oil, grease, etc.
**lu mi nous** (lū′mi-nus): bright; shining by its own light.

**ma chine** (mạ-shēn′): a device or tool that man uses to help him do work.
**mag got** (mag′ọt): an insect, such as a fly, in the soft-bodied, legless stage just after leaving the egg.
**mag ma** (mag′mạ): molten rock inside the earth from which igneous rock or lava is formed.
**mag ne sium** (mag-nē′zhium or mag-nē′shium): a silver-white metallic element which burns with a dazzling white light.
**mag net ic dec li na tion** (mag-net′ik dek-li-nā′shọn): the difference between the true and magnetic north poles or between the true and magnetic south poles.
**magnetic field**: the area in which the force of a magnet acts.
**magnetic lines of force**: a series of invisible lines passing through the space around a magnet from one pole to the other.
**magnetic poles**: the poles of the earth located at some distance from the geographical poles.
**mag net ism** (mag′net-izm): the characteristic of magnets that causes them to attract iron and steel.
**mag net ite** (mag′net-īt): a kind of iron ore that attracts iron and steel as a magnet does.
**mag ne to** (mag-nē′tō): a small machine that uses permanent magnets for producing electric current.
**mass**: the quantity of matter that a body contains.
**matter**: what objects are made of; anything that has weight and fills some space. Matter includes all solid materials, liquid materials, and gases.
**me chan i cal ad van tage** (mẹ-kan′i-kạl ạd-vån′tạj): the ratio of the force produced by a machine to the force applied to it.

**mechanical energy:** energy possessed by moving bodies or by bodies because of their position.
**melting point:** the temperature at which a solid changes to a liquid.
**mer cu ric ox ide** (mėr-kū′rik ok′sīd): a compound of mercury and oxygen.
**mer cu ry** (mėr′kū̦-ri): a metallic element that is liquid at ordinary temperatures.
**me rid i an** (mē̦-rid′i-a̦n): a circle passing through any place on the earth's surface and through the north and south poles.
**me te or** (mē′tē̦-o̦r): a small body of material that falls with great speed from space into the earth's atmosphere.
**me te or ite** (mē′tē̦-o̦r-īt): a mass of stone or metal that has reached the earth from outer space.
**me te or o graph** (mē′tē̦-o̦-rō̦-gräf): an instrument used for recording the temperature, pressure, and humidity of the air.
**met ric** (met′rik) **system:** the system of measurement based on the metre as the standard unit of length and on the kilogram as the unit of weight.
**mi ca** (mī′kä̦): a mineral that splits into thin, partly transparent layers.
**mi crobe** (mī′krōb): a microscopic germ.
**millibar** (mil′li-bar): the pressure exerted by one cubic centimetre of water weighing one gram.
**mold** (mōld): a fungus consisting of a woolly or furry plant growth, often greenish in color. Mold often appears on food or other animal or vegetable substances left too long in a warm, moist place.
**mo lec u lar the o ry** (mō̦-lek′ū̦-lä̦r thē′ō̦-ri): the belief of scientists that all kinds of matter are made of tiny moving particles called molecules.
**mol e cule** (mol′e-kūl or mō′le-kūl): the smallest particle into which a substance can be divided without chemical change.
**moon:** a body that revolves around a planet.
**mo raine** (mō̦-rān′): a pile of material dropped at the end or the sides of a glacier as it melts.
**mor tal i ty** (môr-tal′i-ti): death-rate; loss of life on a large scale.
**mu cous mem brane** (mū′kus mem′brān): the lining of the nose, throat, and other cavities of the body.
**mu cus** (mū′kus): a slimy substance that moistens the linings of the body.
**my ce li um** (mī-sē′li-um): a mass of thread-like material forming part of a fungus, like bread mold.

**nar cot ic** (när-kot′ik): a drug that produces drowsiness, sleep, dullness, or an insensible condition, and lessens pain by dulling the nerves.
**na sal** (nā′za̦l) **passage:** one of the openings from the nostrils to the throat.
**neb u la,** plural **neb u lae** (neb′ū̦-lä̦, neb′ū̦-lē): an irregular-shaped glowing mass of gas or of other galaxies of stars than our own.
**negative charge:** one kind of electrical charge that a body may have, consisting of an excess of electrons over protons.
**negative electricity:** electricity consisting of negative charges.
**ne on** (nē′on): a rare gas, used in television sets and for display signs.
**neu tral** (nū′tra̦l): 1. neither positive nor negative. 2. with the gears in such position that no power is transmitted to the wheels.
**ni trate** (nī′trāt): a compound formed with nitric acid.
**ni tric** (nī′trik) **acid:** a clear, colorless liquid, formed by the action of sulphuric acid on nitrates, which eats into flesh, clothing, metal, etc.
**ni tro gen** (nī′trō̦-jen): one of the elements. Nitrogen is a gas without color, taste, or odor that forms about four-fifths of the air.
**non-con duc tor** (non-ko̦n-duk′to̦r): a material that conducts heat or electricity very slowly or not at all.
**nu cle us,** plural **nu cle i** (nū′klē̦-us, nū′klē̦-ī): an active body within the cell of an animal or a plant, without which the cell cannot grow or divide.

**ob jec tive** (ọb-jek′tiv): a lens nearest the object to be looked at in a compound microscope or telescope.

**oc tave** (ok′tāv): the interval between one musical note and another having twice or half as many vibrations.

**o paque** (ō-pāk′): not letting light through.

**op tic** (op′tik) **nerve**: the nerve which connects the eyes and the brain.

**or bit** (ôr′bit): the path of the earth or any planet around the sun; the path of any heavenly body around another heavenly body.

**or gan** (ôr′gạn): a part of an animal or plant fitted to do a certain thing.

**or gan ic** (ôr-gan′ik): of the bodily organs; affecting the structure of an organ, as, organic disease.

**organic material**: material that was once part of a living thing.

**or gan ism** (ôr′gạn-izm): an individual plant or animal.

**os cil late** (os′i-lāt): move to and fro between two points.

**ox i da tion** (ok-si-dā′shọn): a kind of chemical change in which a material unites with oxygen to form one or more new materials.

**ox ide** (ok′sīd or ok′sid): a compound of oxygen and one other element.

**ox id ize** (ok′si-dīz): combine with oxygen.

**ox y gen** (ok′si-jen): one of the elements. Oxygen is a colorless, odorless gas that forms about one-fifth of the air.

**pan cre as** (pan′krē-as or pang′krē-as): a gland near the stomach that helps digestion.

**pan cre at ic** (pan-krē-at′ik or pang-krē-at′ik) **juice**: the fluid that the pancreas secretes.

**par a site** (par′ạ-sīt): a plant or animal that lives in or on the body of another living thing and takes its food from that living thing.

**pas teur i za tion** (pas′tėr-i-zā′shọn): the process of killing germs in milk by heating it to 144° F. for 30 minutes.

**path o gen ic** (path-ō-jēn′ik): disease-producing.

**pel lag ra** (pe-lag′rạ or pe-lā′grạ): a disease caused by the lack of a certain vitamin.

**pel vis** (pel′vis): the basin-shaped bony structure between the hips.

**pep sin** (pep′sin): a substance in the gastric juice of the stomach that digests meats, eggs, cheese, and similar foods.

**per cus sion** (pėr-kush′ọn) **instruments**: musical instruments that are played by striking them.

**per i scope** (per′i-skōp): a device consisting of an arrangement of mirrors or prisms in a tube, by which things may be seen from below or behind.

**pet ri fied** (pet′ri-fīd): changed to stone.

**pe tro le um** (pē-trō′lē-um): an oily, dark-colored liquid found in the earth, from which gasoline, kerosene, etc., are made.

**phar ynx** (far′ingks): the cavity at the back of the mouth where the passages to the nose, lungs, and stomach begin.

**phase** (fāz): apparent shape of the moon or of a planet at a given time. The four phases of the moon are the new moon, the first quarter, the full moon, and the last quarter.

**pho to-e lec tric** (fō′tō-ē-lek′trik) **cell**: a cell so constructed as to cause fluctuations in electric current due to its sensitivity to variations in light.

**pho to syn the sis** (fō-tō-sin′the-sis): the chemical change by which green plants make starch from water and carbon dioxide with the help of sunlight and chlorophyll.

**pis ton** (pis′tọn): flat, round piece of wood or metal fitting closely inside a tube, or hollow cylinder, in which it is moved back and forth by some force.

**pitch**: 1. in music, the degree of highness or lowness of a sound. 2. of a screw, the distance between the centres of two threads.

**plan et** (plan′et): a heavenly body that moves around the sun.
**plan e toid** (plan′e-toid): a small planet that revolves around the sun.
**plas ma** (plaz′mạ̈): the watery part of blood or lymph.
**plas tic** (plas′tik): putty-like; easily molded or shaped.
**pla teau** (pla-tō′): an elevated area of land.
**pneu mat ic** (nụ̄-mat′ik): worked by air-pressure.
**Po la ris** (pọ̄-lā′ris): the North Star.
**pole**: 1. either end of the earth's axis. 2. one of the places on a magnet where the force is strongest.
**positive charge**: one kind of electrical charge that a body may have, consisting of an excess of protons over electrons.
**positive electricity**: electricity consisting of positive charges.
**po tas si um** (pọ̄-tas′i-um): a soft silver-white metallic element, occurring in nature only in compounds.
**po ten tial** (pọ̄-ten′shạl) **energy**: stored-up energy possessed by materials because of their chemical composition, their position, or their condition.
**pow er** (pou′ėr): 1. energy or force that can do work. 2. the rate at which a machine can do work.
**pre cip i tate** (prẹ̄-sip′i-tāt): 1. condense (moisture) from vapor in the form of rain, dew, snow, etc. 2. separate (a substance) out in solid form from a solution.
**pres sure** (presh′ụ̄r): force exerted upon a unit of area.
**preventive medicine**: the measures taken to prevent diseases before they occur rather than to cure them after they occur.
**pri ma ry** (prī′mạ-ri) **coil**: the coil of a transformer that, by its magnetic effect, generates current in another coil, called the secondary coil.
**prime meridian**: the meridian that passes through Greenwich, England. It is taken as 0° longitude and used to measure longitude east and west.
**prism** (prizm): a solid, triangular-shaped piece of glass that will separate white light passing through it into the colors of the rainbow.
**prop er ty** (prop′ėr-ti): a characteristic of an organism or a substance that helps to tell what it is.
**pro te in** (prō′tẹ̄-in): a food material containing nitrogen in addition to carbon, hydrogen, and oxygen. It is used for making new protoplasm.
**pro ton** (prō′ton): a tiny particle carrying a positive charge of electricity.
**pro to plasm** (prō′tọ̄-plazm): the clear syrup-like material that is the living part of all plant and animal cells.
**pul ley** (pul′i): a wheel with a hollowed rim in which a rope can run, and so lift weights or change the direction of the pull.
**pul mo na ry** (pul′mọ̄-nạ̄-ri) **vein**: a large blood vessel which collects the purified blood in the lungs and returns it to the heart.
**pul sa ting** (pul′sā-ting) **current**: electric current that changes from a strong one to a weak one, back to a strong one, and so on.
**pulse** (puls): the beating of the heart; the changing flow of blood in the arteries caused by the beating of the heart.
**pu pa**, plural **pu pae** (pū′pạ̈, pū′pē): a stage in the life of an insect when it is in a case. It comes between the larva and the winged adult stage.
**pu pil** (pū′pil): the black centre of the eye in the iris. It opens and contracts according to the intensity of light.
**pus** (pus): the whitish or yellowish, watery material that collects in sores.

**quality**: the character of a tone that makes it possible to tell it from another tone of the same pitch and intensity.
**quar an tine** (kwor′ạn-tēn): the keeping of persons, etc., having infectious disease away from others to prevent an epidemic.
**quartz** (kwârts): a clear, glass-like, and hard mineral composed of the elements silicon and oxygen. Sand is mostly quartz.

**ra bies** (rā′bēz or rā′bi-ēz): the disease of a mad dog.
**ra di ant** (rā′di-ant) **energy**: energy in the form of visible or invisible rays from some heated source.
**radiant heat**: invisible radiant energy of a kind that changes to heat when it strikes something and is absorbed.
**ra di ate** (rā′di-āt): give out rays of light, radiant heat, etc.
**ra di a tion** (rā-di-ā′shon): giving out rays of light, radiant heat, etc.
**ra di a tor** (rā′di-ā-tor): a part of the cooling system of a gasoline engine.
**ra di o ac tive** (rā′di-ō-ak′tiv): used to describe an element like radium that gives out heat energy all the time as it changes into other substances.
**ra di um** (rā′di-um): a radioactive metallic element.
**rar e fac tion** (rar-ē-fak′shon or rār-ē-fak′shon): the part of a sound wave in which the air molecules are spread apart.
**ray on** (rā′on): artificial fabric resembling silk, made from wood pulp or cotton.
**re ac tion** (rē-ak′shon) **time**: the time that it takes for a person to react to a stimulus.
**re ceiv er** (rē-sē′vėr): the part of a telephone that receives electric current from the transmitter and changes it back to sound waves.
**re cip ro ca ting** (rē-sip′rō-kā-ting) **motion**: back-and-forth motion.
**rec ti fy** (rek′ti-fī): change an alternating current to a direct current.
**rec ti lin e ar** (rek-ti-lin′ē-är): moving in a straight line.
**re flect** (rē-flekt′): throw back (light, heat, sound, etc.).
**re flec tion** (rē-flek′shon): the throwing back of light, heat, sound, etc.
**re fract** (rē-frakt′): bend (light, etc.) from a straight course.
**re frac tion** (rē-frak′shon): the bending of light, etc., from a straight course.
**re frig er a tion** (rē-frij-e-rā′shon): the process of cooling or keeping cool.
**re sist ance** (rē-zis′tans): in electricity, friction.
**res o na tor** (rez′ō-nā-tor): a device for making sound louder and longer by reflection or sympathetic vibrations.
**res pi ra tion** (res-pi-rā′shon): 1. the chemical change in cells in which oxygen is used to secure energy from foods and carbon dioxide is thrown off. 2. the taking of oxygen into the body and giving out of carbon dioxide.
**re spir a to ry** (rē-spīr′a-tō-ri or res′pi-ra-tō-ri) **system**: the breathing system.
**re sponse** (rē-spons′): something done by a living thing when it receives a stimulus; some act caused in the body.
**ret i na** (ret′i-nä): the layer of cells at the back of the eyeball that is sensitive to light and receives the images of things looked at.
**rev o lu tion** (rev-ō-lū′shon): moving in a circle or curve around a point.
**re volve** (rē-volv′): move in a circle or curve around a point.
**rhe o stat** (rē′ō-stat): an instrument for regulating the size of an electric current by introducing different amounts of resistance into the current.
**rick ets** (rik′ets): a childhood disease caused by lack of proper vitamins and of sunshine, which results in softening and sometimes bending of the bones.
**root-hair**: fine thread-like part that extends from the young parts of roots.
**ro ta ry** (rō′ta-ri) **motion**: circular motion, such as that of a wheel.
**ro tate** (rō′tāt): 1. turn around a centre or axis. 2. change in a fixed order.
**ro ta tion** (rō-tā′shon): 1. turning around a centre or axis. 2. changing in a fixed order.
**ro tor** (rō′tor): the rotating part of a machine or apparatus.
**rust**: 1. iron oxide, a reddish-brown material formed on iron when it is exposed to air or moisture: 2. a mold-like plant parasite that lives on the stems and leaves of wheat and other crops.

**sac** (sak): a bag-like part in a plant or animal, as, the air sacs in the lungs.
**sa li va** (sa-lī′vä): the liquid produced by glands in the mouth that helps dissolve food.

**sal i va ry** (sal′i-vā̤-ri) **gland:** the group of cells that produce saliva.
**sap ro phyte** (sap′rọ̄-fīt): a plant that gets its food from plants or animals that have died.
**sat el lite** (sat′e̤-līt): a moon or any body that revolves around a planet.
**sat u rate** (sat̤′ṳ̄-rāt): soak thoroughly; fill full.
**screw:** a type of inclined plane consisting of a cylinder having a spiral ridge running around it.
**scur vy** (skėr′vi): a disease due to lack of proper vitamins and fruits and vegetables.
**sec on da ry** (sek′o̤n-dā̤-ri) **coil:** the coil of a transformer in which current is generated by the magnetic action of another coil, called the primary coil.
**se crete** (sē̤-krēt′): make; prepare; produce.
**sed en ta ry** (sed′e̤n-tā̤-ri): that keeps one sitting still a good deal.
**sed i ment** (sed′i-me̤nt): material carried by liquid, which gradually settles to the bottom.
**sed i men ta ry** (sed-i-men′ta̤-ri) **rock:** rock layer formed from sediment in water.
**seep age** (sē′pā̤j): leakage; slow passing through.
**sep tic** (sep′tik) **tank:** a place where waste materials are completely decomposed by bacteria and drained off into the soil.
**ser um** (sēr′um): a liquid used to prevent or cure a disease, obtained from the blood of an animal that has been made immune to the disease.
**sex tant** (seks′ta̤nt): an instrument used to determine longitude and latitude by finding the angle of the sun with the horizon at noon.
**shale** (shāl): a sedimentary rock made of hardened clay, etc., that splits readily into thin layers.
**simple machine:** a simple device that transmits and modifies force.
**si nus** (sī′nus): one of the small pockets in the bones of the head.
**skel e tal** (skel′e̤-ta̤l): having to do with the skeleton.
**slate:** a bluish-gray rock that splits easily into thin smooth layers.
**slip rings:** insulated rings on the shaft of an alternating-current generator that help transmit the current from the armature to the outside circuit.
**so di um chlo ride** (sō′di-um klō′rīd): the chemical name for table salt, a compound made of two elements, sodium and chlorine.
**so lar** (sō′lä̤r) **system:** the sun and all the planets that revolve around it.
**solid:** the form of matter that takes up a certain amount of space and keeps its shape.
**sol u ble** (sol′ṳ̄-bl): that can be dissolved.
**so lu tion** (so̤-lū′sho̤n): liquid in which another substance has been dissolved.
**sol vent** (sol′ve̤nt): a substance which dissolves other substances.
**so nom e ter** (sọ̄-nom′e-tėr): an instrument for experimenting with vibrating strings.
**sounder:** receiving instrument by whose sounds a telegraph message is read.
**sounding-board:** a board behind the strings of a piano that reënforces the sound made when the hammers strike the strings.
**sound in su la tor** (in′sṳ̄-lā-to̤r): a porous or flexible material that transmits sound waves very poorly.
**spe cif ic grav i ty** (spē̤-sif′ik grav′i-ti): the weight of any given volume of a substance as compared with the weight of an equal volume of water.
**spec tral** (spek′tra̤l) **color:** one of the pure colors of the spectrum.
**spec tro graph** (spek′trọ̄-gräf): an instrument for taking a picture of the band of colors formed when a ray of light from any source is broken up.
**spec tro scope** (spek′trọ̄-skōp): an instrument for obtaining and examining the band of colors formed when a ray of light from any source is broken up.
**spec trum** (spek′trum): the band of colors into which white light is separated when it is passed through a prism.

**spi nal** (spī′na̤l) **cord:** a cord of nerve tissue inside the backbone.
**spi ril lum,** plural **spi ril la** (spī-ril′um, spī-ril′ạ): any of the spiral-shaped bacteria.
**spon ta ne ous com bus tion** (spon-tā′nẹ̄-us kọm-bus′chọn): the bursting into flame of oily rags, coal in large piles, etc., because of the great heat produced by the uniting of oxygen with the material.
**spontaneous gen er a tion** (jen-ẹ-rā′shọn): the theory that living things are produced from non-living matter.
**spu tum** (spū′tum): saliva; spit.
**sta lac tite** (stạ-lak′tīt or stal′ak-tīt): a formation of lime material shaped like an icicle, hanging from the roof of a cave.
**sta lag mite** (stạ-lag′mīt or stal′ag-mīt): a formation of lime material shaped like a cone, built up on the floor of a cave.
**state of matter:** the form in which matter exists, that is, as a solid, a liquid, or a gas.
**stat ic** (stat′ik) **electricity:** electric charges on bodies such as are produced by rubbing one material on another.
**step-down transformer:** a transformer that reduces the voltage of an alternating electric current.
**step-up transformer:** a transformer that increases the voltage of an alternating electric current.
**ster ile** (ster′il): free from living germs.
**ster il i za tion** (ster′il-i-zā′shọn): freeing from living germs.
**ster il ize** (ster′il-īz): make free from living germs.
**steth o scope** (steth′ọ̄-skōp): an instrument used by doctors to hear sounds in the body.
**stim u lus,** plural **stim u li** (stim′ụ̄-lus, stim′ụ̄-lī): something that brings about a response in a living thing; something that causes some part of a body to act.
**sto ma,** plural **sto ma ta** (stō′mạ̈, stō′mạ-tạ̈): small opening in the skin of a leaf, protected by guard cells.
**storage cell:** a cell for generating current that can be recharged by running a current of electricity through it.
**stra ta** (strā′tạ̈): layers of earth or rock.
**strat i fied** (strat′i-fīd) **rock:** rock arranged in layers.
**stra to sphere** (strā′tọ̄-sfēr): thin air about 7 miles and more above the earth.
**stra tus** (strā′tus): a layer-like cloud of low altitude.
**strep to coc cus** (strep-tọ̄-kok′us): any of the ball-shaped bacteria. Often they stay attached in the form of a chain.
**stri ae,** singular **stri a** (strī′ē, strī′ạ̈): scratches and grooves left on the surfaces of rocks over which glaciers have passed.
**sul phate** (sul′fāt): a compound formed with sulphuric acid.
**sul phu ric** (sul-fū′rik) **acid:** a heavy, colorless, oily, very strong acid.
**sun time:** time in which noon is the moment when the sun is directly overhead.
**sus cep ti ble** (su-sep′ti-bl): especially liable, as, susceptible to disease.
**sus pen sion** (sus-pen′shọn): the state of a solid when its particles are mixed with but not dissolved in a liquid, gas, or another solid.
**sym bol** (sim′bọl): the letter or letters that stand for an element or an atom of an element, as O for oxygen.
**sym pa thet ic vi bra tion** (sim-pạ-thet′ik vī-brā′shọn): vibration produced in one body by waves of the same number of vibrations per second in another body.
**symp tom** (simp′tọm): a sign; an indication.
**syn chro nous** (sing′krọ̄-nus): going on at the same rate and exactly together.
**syn thet ic** (sin-thet′ik): made by combining parts or elements into a whole.
**sys tem** (sis′tem): set of organs in the body, all helping in one kind of work, as, the circulatory system.

**tap-root:** the main root of a plant.
**te le type wri ter** (tel-ẹ̄-tīp′rī′tėr): a machine that receives the messages from a telegraph receiver and automatically types them out.
**tel e vise** (tel-ẹ̄-vīz′): transmit and reproduce by television.
**te le vi sion** (tel-ẹ̄-vizh′ọn): the transmission and reproduction of the images of distant persons or scenes by radio.
**ten don** (ten′dọn): tough, strong band or cord that joins a muscle to a bone.
**tet a nus** (tet′ạ-nus): lockjaw, a disease that causes violent spasms, stiffness of many muscles, and even death.
**the o ry** (thē′ọ̄-ri): an explanation based on observation and reasoning.
**ther mo graph** (thėr′mọ̄-gräf): an instrument that makes a record of the temperature for a day, a week, or longer.
**ther mo stat** (thėr′mọ̄-stat): an automatic device for regulating temperature.
**tho rax** (thō′raks): the cavity of the chest.
**thy roid** (thī′roid) **gland:** a gland in the lower front part of the neck that is very important to health.
**tis sue** (tish′ọ̈): a mass of cells arranged to form parts, such as bones, muscles, skin, etc., of animals and plants.
**tour ni quet** (tör′ni-ket): a device to stop bleeding by compressing a blood-vessel. A bandage tightened by twisting a stick is one kind.
**tox in** (tok′sin): a poison produced in animals or plants by germs.
**tox in-an ti tox in** (tok′sin-an-ti-tok′sin): a mixture of toxin and antitoxin that gives the body active immunity.
**tra che a** (trā′kẹ̄-ạ̈): the windpipe; air passage from the throat to the lungs.
**trans form er** (trans-fôr′mėr): a device for changing the voltage of an alternating electric current.
**trans lu cent** (trans-lū′sẹnt): letting light through, but not transparent.
**trans mit ter** (trans-mit′ėr): 1. the part of a telephone into which one speaks. 2. the part of a telegraphic instrument by which a message is sent.
**trans par ent** (trans-pãr′ẹnt): easily seen through.
**tri chi na** (tri-kī′nạ̈): a small worm that sometimes lives in the muscles of men, hogs, and other animals, causing disease.
**trich i no sis** (trik-i-nō′sis): a disease caused by the trichina.
**tset se** (tset′sē) **fly:** a blood-sucking insect of Africa, the bite of which transmits the germ of sleeping sickness to man, cattle, etc.
**tu ber cle** (tū′bėr-kl): small, round knob or swelling on the roots of legumes.
**tu ber cu lin** (tụ̄-bėr′kụ̄-lin) **test:** test to find out if one has tuberculosis.
**tu ber cu lo sis** (tụ̄-bėr-kụ̄-lō′sis): a disease affecting various tissues of the body, but most often the lungs.
**tung sten** (tung′stẹn): a rare metallic element used in making steel and for electric-lamp filaments.
**tur bi nate** (tėr′bi-nāt) **bones:** the flat, folded bones of the inner nose, extending into the passage.
**tur bine** (tėr′bin or tėr′bīn): an engine or motor in which a wheel with vanes is made to revolve by force of water, steam, or air.

**ul tra-vi o let** (ul′trạ̈-vī′ọ̄-let) **rays:** certain invisible rays of the sun. Some ultra-violet rays help make vitamin D in the body; others cause sunburn.
**un con for mi ty** (un-kọn-fôr′mi-ti): the surfaces between layers of older rock and layers of newer rock, showing that changes have occurred between the times of formation of the layers.
**u ni verse** (ū′ni-vėrs): all the heavenly bodies and the vast spaces between them.
**U ra nus** (ū′rạ-nus): one of the nine known planets circling around the sun.
**u rine** (ū′rin): the fluid containing waste matter taken from the blood by the kidneys, which goes to the bladder and is then discharged from the body.

**vac ci na tion** (vak-si-nā′shọn): the process of injecting vaccine under the skin to produce a mild form of a disease as protection against the real disease.

**vac cine** (vak′sēn or vak′sin): a substance injected under the skin to produce a mild form of a disease, used for protection against the real disease.

**vac u um** (vak′ụ̄-um): an empty place from which everything, including air, has been removed.

**vas cu lar** (vas′kụ̄-lạ̈r) **bundles**: round bundles of long cells, running lengthwise of the stem of a plant. They carry water and minerals from the roots to the leaves, food down to the stems and leaves, and support the entire plant.

**vein** (vān): 1. one of the blood vessels or tubes that carry blood to the heart from all parts of the body. 2. a rib of a leaf.

**ven tri cle** (ven′tri-kl): one of the two lower chambers of the heart which receive blood and force it into the arteries.

**ver te bra**, plural **ver te brae** (vėr′tẹ̄-brạ̈, vėr′tẹ̄-brē): one of the bones of the backbone.

**ver te brate** (vėr′tẹ̄-brāt): 1. having a backbone. 2. animal with a backbone.

**vil lus**, plural **vil li** (vil′us, vil′ī): one of the thousands of tiny finger-like projections in the small intestine of the body that help to absorb food.

**vi rus** (vī′rus): a liquid or other material that will cause an infectious disease if put into the blood. Usually virus means a material in which no germs can be found, yet which will cause a disease like smallpox, measles, etc.

**vi ta min** (vī′tạ-min): one of certain special substances in foods, needed in very small amounts to keep the body healthy. Vitamins are found especially in milk, butter, raw fruits and vegetables, and cod-liver oil.

**vo cal** (vō′kạl) **cords**: membranes in the throat, the lower of which can be pulled tight or loosened to help make the sounds of the voice.

**vol can ic** (vol-kan′ik) **ash**: dry ash-like material formed when the air cools bits of melted rock that burst out of an erupting volcano.

**volt** (vōlt): the unit used to measure electrical pressure.

**volt age** (vōl′tạ̄j): electrical pressure measured in volts.

**volt me ter** (vōlt′mē′tėr): an instrument for measuring the number of volts of an electric circuit.

**water table**: the top of the saturated soil.

**watt** (wot): 1. unit for measuring power; about 44 foot-pounds per minute. 2. power of a current of one ampere flowing under a pressure of one volt.

**watt-hour** (wot′our): the amount of energy used by a device that uses one watt for one hour.

**watt-hour meter**: an instrument that measures the number of watt-hours of electric energy used in a building over a period of time.

**weathering**: the process of softening and breaking up rocks as a result of the chemical action of air and water on them.

**wedge**: a piece of wood or metal with a thin edge used in splitting, separating, etc.

**weight-arm**: the distance from the weight to the fulcrum in a lever.

**wheel and axle**: a simple machine consisting of a wheel or a crank fixed to a bar or shaft.

**work**: moving something by pushing or pulling it. The amount of work done depends on how hard one pushes or pulls and on how far the object is moved.

**x-ray** (eks′rā′): a special kind of invisible rays used to locate breaks in bones, to examine teeth, to treat certain diseases, etc.

**yeast** (yēst): a plant organism that develops quickly in sweetened liquid.

# Index

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tHESE are the
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